Established by BENJAMIN SILLIMAN in 1818.

PUBLIC LIBRARY

THE

AMERICAN JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE, W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS, L. V. PIRSSON AND H. E. GREGORY, OF NEW HAVEN,

PROFESSOR GEORGE F. BARKER, OF PHILADELPHIA,
PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXII—[WHOLE NUMBER, CLXXII.]

No. 129—SEPTEMBER, 1906.

NEW HAVEN, CONNECTICUT.

1906

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

CRYSTALS, FINE MINERAL SPECIMENS,

METEORITES.

Orders amounting to $20 or over sent carriage paid on approval, with the privilege of selection. Rejected material returned at consignee's expense.

Send for our illustrated descriptive Catalog of "Choice Minerals" just published.

SYSTEMATIC COLLECTIONS

Of Typical Specimens,

In sets of twenty-five up to fifteen hundred specimens. Prices $5.00 upwards per set, the average price for students' specimens (average size $2\frac{3}{4}'' \times 2''$) being about twenty cents. For 30 years we have been supplying reference specimens to the mining schools, universities and museums throughout the world. We refer to any curator or professor of mineralogy or geology.

OUR LABELS accompany every specimen, giving correctly,—name, chemical composition and locality.

QUALITY is guaranteed in our prepayment of transportation to any address in the world (on orders of $20 or more). We could not take this transportation risk, if the quality did not insure your keeping them, as we refund money on minerals promptly returned.

PRICES are the lowest, as comparison will show. The volume of our trade permits it.

FREE COLLECTION CATALOG, containing lists and illustrations of General Mineral Collections, Series of Ores for Prospectors, Sets of Crystals, Series illustrating Hardness and other Physical Characters of Minerals, with price List of Laboratory Material and Individual Specimens.

FOOTE MINERAL CO.,

Established 1876, by Dr. A. E. Foote.

W. M. Foote, Manager.

DEALERS IN

Mineral Specimens and Commercial Rare Minerals.

Removed to

107 N. 19th St., Philadelphia, Pa., U. S. A.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XVIII.—*Abyssal Igneous Injection as a Causal Condition and as an Effect of Mountain-building;* by REGINALD A. DALY, Ottawa, Canada.

[Published by permission of the Canadian Commissioner, International Boundary Surveys.]

CONTENTS.

Introduction.
The shells of compression and tension in the earth.
The hypothesis of a crust and fluid substratum.
Purpose of the present paper; acknowledgments.
Thickness of the earth's crust.
Compression of the substratum; flotation of the crust.
Stresses within the crust.
Secular accumulation of tension and of cooling cracks.
Injection of magma into the shell of tension.
Relief of tensions through abyssal injection.
Down-warping of the surface as a result of abyssal injection.
The conditions for mountain-building.
Expansion of the earth's outer shell as a factor in mountain building.
Renewed abyssal injection following mountain-building; development of batholiths.
Vulcanism as a result of mountain-building.
Summary.
Postulates.
Conclusions.

INTRODUCTION.

The shells of compression and tension in the earth.—Whether the earth, as it cools and contracts, be solid and highly rigid throughout, or whether it consist of a solid crust with an underlying fluid substratum, it is generally held by geologists that there is a "level of no strain" beneath the surface. The depth of this level has been computed for a solid earth by Davison and Darwin, who have made various assump-

tions which are more or less reasonable provided the fact of complete solidity is established. Their estimates for the depth of the zero-strain level vary from 2 miles to 7·79 miles.* With analogous assumptions Fisher has calculated that there will similarly be a level of zero-strain in a crust overlying the fluid substratum of a globe solidifying from the circumference inwards. He found that "if the time elapsed since a crust began to be formed has been 100 million years, the depth of the level of no strain at the present time will be about four miles."† In any case the depth increases very slowly with the time elapsed since the crust first formed.

Rudski has pointed out that, if the earth's initial temperature were not uniform, the level of no strain would, in a given time, be deeper than by the amount calculated on the assumptions of Davison.‡ It is, in truth, probable that the initial temperature increased downwards. We shall see that there is a grave reason for doubting the conclusion of Kelvin that an initial uniform temperature was secured through the foundering of early crusts. The suggestion of LeConte that it might be secured through the operation of convection currents is not acceptable to those who hold the very probable view that the earth's internal density increases downward, not only because of increasing pressure but because of differences in chemical composition as well.§

All of these calculations have been made on the supposition that the thermometric conductivity of the material of the earth is a constant quantity. It is, however, most probable that this conductivity decreases with rise of temperature and very greatly increases on the passage of liquid magma into solid rock. Forbes showed that the "calorimetric" conductivity of iron decreases with rise of temperature, as illustrated in the following table, which is an abridged form of his experimental results:‖

* C. Davison, Philosophical Transactions, Royal Society of London, vol. clxxviiiA, p. 231, 1887; G. H. Darwin, ibid., p. 242; C. Davison, Proceedings of the Royal Society of London, vol. lv, p. 141, 1894. Cf. M. Reade, Origin of Mountain Ranges, London, 1886, p. 121.

† O. Fisher, Physics of the Earth's Crust, London, 2d ed. 1891, appendix, p. 45.

‡ M. M. P. Rudski, Philosophical Magazine, vol. xxxiv, p. 299, 1892.

§ Cf. J. LeConte, American Geologist, vol. iv, p. 43, 1889. It may be noted that, in the above-mentioned calculations, no account has been taken of the special and important contraction characterizing the passage of lava from the liquid to the solid state, nor, except in the case of Fisher's estimates, for the fact that, with a given fall of temperature, liquid lava (diabase) contracts about twice as much as solid lava (Barus, Bull. U. S. Geological Survey, No. 103, 1893).

‖ J. D. Forbes, Trans. Roy. Soc. Edinburgh, xxiv, p. 105, 1867.

Temperature.	Conductivity 1st specimen.	Conductivity 2d specimen.
0°C	12·42	9·21
50	10·63	8·37
100	9·40	7·76
150	8·68	7·38
200	8·14	7·10

Units in centimeter, minute and deg. Centigrade.

Similarly, Weber measured the conductivity of gneiss at 0°C and at 100°C and found the conductivity to be 578/416 greater at the lower temperature than at the higher.*

Barus proved that the thermometric conductivity of the substance thymol increased 56 per cent in passing from the liquid to the solid state at the same temperature (possible through undercooling).†

It is true that condensation through pressure increases the conductivity for heat, but Arrhenius has pointed out that at depths greater than only a small fraction of the earth's radius, increment of pressure entails no corresponding increment of condensation.‡ This condition applies to the (gaseous) earth-matter which, at the depth of several hundred miles, has reached its co-volume. At this and at greater depths temperature may be in complete control as regards the conductivity for heat—an increase of temperature with still greater depth involving a slow decrease of conductivity.

These observations and conclusions indicate, first, that experimental studies on the conductivity of rock-matter at different temperatures, in different states of compression, and in the two states of aggregation (if such studies are possible), are urgently needed; secondly, that it is now impossible to calculate the exact position of the level of no strain in the earth's crust. Nevertheless, in an earth composed of a crust floating on a substratum which, because it is fluid and hot, has a lower thermometric conductivity than the solid, cool crust, we might expect the level of no strain to be well within the crust even if the initial temperature gradient were comparable to that now observed in the earth's superficial shell. In a personal letter to the writer, the Rev. Osmond Fisher states that, with a liquid interior, there must be a level of no strain in the crust; and this is apparently true no matter what the initial temperature may have been. He states, further, that "the level of no strain would be the same whatever the conductivity; but the time would not be the same. The position of the level would not fall so rapidly if the conductivity was less."

* R. Weber in Landolt and Börnstein's Phys. Chem. Tabellen.

† C. Barus, this Journal, vol. xliv, p. 15, 1892.

‡ S. Arrhenius, Geol. Fören. Stockholm Förhandlingar, vol. xxii, pp. 396–7, 410, 1900.

The shell above the zero-strain level is under tangential compression. The shells beneath that level, for a considerable distance downwards, are under tension. On account of the weight of all overlying shells any shell below the zero-strain level tends to be stretched or (using Reade's term) to suffer "compressive extension." This tendency increases with depth to a maximum in a level computed by Davison for a solid earth to lie 72 miles below the surface. The corresponding level for an earth with a fluid substratum has been calculated by Fisher to lie at depths of from 30 to 55 miles, depending among other conditions on the temperature of solidification.*

The hypothesis of a crust and fluid substratum.—There are many reasons why the doctrine of the earth's complete solidity is not acceptable to the working geologist. Some of the cogent arguments against it have been summarized by De Lapparent† and other able writers on the theory of the globe. The strength of these arguments is great and by so much favors the opposed doctrine of a fluid substratum supporting a solid crust. The astronomic evidence for the hypothesis of complete solidity rested at first on the calculations of Hopkins in his well known paper on the combined effect of tidal pull and internal fluidity upon the precession of the equinoxes. Later analyses by Kelvin and Darwin proved that Hopkins' conclusions could afford no "decisive argument against the earth's interior liquidity." "Here we have a remarkable instance of the final abandonment of an argument, which, from the portentous difficulties of comprehending it, had proved too hard for geologists to assail."‡

The stronger argument, based by Kelvin and Darwin on the observed and calculated magnitude of oceanic tides, has likewise suffered destructive criticism by Fisher. The various discussions on this most complicated subject show clearly that not enough is known either of the constitution of matter or of the oceanic tides themselves to permit of certain mathematical determination of the earth's true rigidity. Fisher's luminous work seems to prove that the geologist may still accept as the best working hypothesis the view that the earth's "crust" is a true crust and rests on a shell of fluid magma. Fisher has demonstrated that, if the substratum is saturated with water-gas, the bodily tide of the earth may entirely disappear, its place being taken by a density tide in the substratum. This would be true on account of the compressibility of the substratum.§ Since glass and presumably igneous magma are not only

* Op. cit., p. 106.

† See the chapters on vulcanism in his "Traité de Géologie."

‡ O. Fisher, op. cit., p. 38.

§ O. Fisher, op. cit., p. 61.

somewhat compressible but almost perfectly elastic, the same reasoning may possibly apply to an anhydrous substratum.* Again, the recently developed view that the great nucleal mass of the earth is composed of true gas immensely compressed, must also be reckoned with in the attempt to prove rigidity by the oceanic tides.

Purpose of the present paper; acknowledgments.—While the question as to how much of the earth is fluid is now quite open, the hypothesis of crust and fluid substratum has many special points of advantage. Many writers have shown how it agrees with essential observations on the structure and history of the rocks accessible at the earth's surface. It appears, however, that important consequences of the hypothesis, consequences involved in the correlation of subsurface tensions with igneous intrusion, surface deformation and mountain-building, have, so far as known to the writer, never been systematically deduced. This paper is intended to form a brief and but qualitative treatment of the subject.†

The writer has pleasure in acknowledging the great courtesy of Professor F. D. Adams, who afforded much help in discussing such physical constants of rocks as form data required in the following hypothesis. Special thanks are due to Dr. A. C. Lane, who has, by correspondence, discussed anew the relation between subsurface tensions and the gases evolved from the earth's interior; also to the Rev. O. Fisher and to Professor L. V. Pirsson, who, similarly by correspondence, have offered valued suggestions. But, in justice to these investigators, it may be added that they should be clearly absolved from all responsibility in launching this new hypothesis on the sea of discussion, which has borne whole fleets of older hypotheses of mountain-building, has sunk many of them, and still floats the more or less battered but more seaworthy hypotheses. The ribs of this new vessel are few—assumptions which themselves may long have to remain in the workshop of geological opinion; to these the planks of argument have been fastened and again there is a chance that the vessel is neither tight nor trim. Each postulate and almost every argument of the hypothesis well merits a whole article to itself, but their elaboration or destruction may wisely be left to more skilful hands. This paper is little more than the barest statement of a suggestion which is offered expressly for criticism. The necessary brevity of treatment forbids that constant, explicit reference

* Lord Kelvin states that crystals and glasses probably possess elasticity of volume "to perfection"—art. "Elasticity" in the Encyclopaedia Britannica, 3d paragraph.

† The relative merits of the planetesimal and nebular hypothesis of the earth's origin are not discussed, but the older hypothesis may be regarded as basal to the argument.

be made to the actual facts of outdoor nature which would be essential to a thorough presentation of the hypothesis, but it is true that each argument has been made, as far as possible to the writer, with attention to observations in the field. In fact, it has been the direct call for some kind of explanation of structures and rock-associations in the British Columbia mountains that has prompted this hypothesis. The principle of advancing reasonable deduction beyond the region of observed fact needs no apology. Nowhere in dynamic geology is an appeal to the realm of the unseen more necessary than in the problems of orogeny and igneous intrusion. These problems have already reached the stage where more observations on the visible part of the earth-crust are not so fundamentally necessary as the reference of the abundant, now accessible, and well recorded observations to an intelligent imagining of the gigantic forces and processes resident in the earth's invisible interior. The orology of the future, even more than that of the past, must rest on well-regulated speculation.

The hypothesis is phrased in terms of a solid crust floating on a liquid substratum. It is possible that gases originally absorbed in the substratum, according to the conception of Lane,* should also be considered; but, on a following page, a reason for excluding them from any large share in crustal deformation is briefly noted. On that ground and because of the relative simplicity secured for the hypothesis as set forth, the dynamic influence of the absorbed gases is not discussed. It will be seen, however, that the expansional energy of gases possibly given off during the solidification of the substratum would furnish a condition favorable to the hypothesis.

Thickness of the Crust.—The depth of the level where the fluid substratum is first encountered has been estimated in several ways. Of these estimates, that founded on the most reliable determinations of the temperature gradient and of the relation between pressure and the fusion point, is clearly preferable. Kelvin has shown that for about 25 miles of depth the gradient would be essentially rectilinear in a cooling globe. The generally accepted gradient is approximately one degree Centigrade for 100 feet of depth. This gradient implies that at the depth of about 22·5 miles a gabbroid magma would possess the temperature appropriate to complete fusion at atmospheric pressure; (diabase melts at 1170° C. and solidifies at 1095° C.—Barus). Vogt has recently calculated that the pressure of 22·5 miles of rock would raise the fusion-point about 50°C.†

* Bull. Geological Society of America, vol. v, 1894, p. 259.

† J. H. L. Vogt, Die Silikatschmelzlösungen, part 2, Videnskabs-Selskabets Skrifter, I. Math.-naturv. Klasse, Christiania, 1901, p. 210.

Completely fluid gabbroid magma would therefore not be expected at a depth short of 24 miles even if the temperature gradient were truly rectilinear. Allowing an extra mile of depth to correspond to a possible slight weakening of the gradient at these depths, it follows that a shell of gabbro at the depth of 25 miles might be completely fluid. The enormous predominance of basalt in the world's lava-fields, especially among the lava-floods of fissure eruptions, suggests the strong probability that the fluid material immediately beneath the crust has actually the composition of gabbro. It thus appears permissible to regard 25 miles as representing nearly the thickness of the crust.

The strong compression of the substratum would decrease the average intermolecular distance and thus increase the viscosity, but the material remains a true liquid. Though the viscosity of such a liquid is high, yet the possibility of its infinite deformation and its capacity of transmitting pressures hydrostatically are, in the long periods of geological time, as perfect as if the substratum were comparable to water in fluidity. Its material is a true fluid and not a solid either rigid or plastic. If, however, the substratum material, still preserving its high temperature, is injected into higher levels in the crust, where pressures are less, it may become highly mobile under small stresses. "It is important to remember, too, that the very act of flow of a viscous fluid, by the definition of viscosity, produces internal friction and additional heat and renders it more fluid."*

Compression of the substratum; flotation of the crust.—The gabbroid substratum at its upper surface bears a pressure of about 12,000 atmospheres. This vast pressure must compress magma very considerably. Barus has demonstrated that liquid napthalene is about four times more compressible than solid napthalene at the same temperature.† If gabbro obeys the same law even approximately under the assumed conditions of pressure and temperature, it is possible to estimate roughly the density of the uppermost shell of the substratum. Let it be assumed, for example, that the specific gravity of crystallized gabbro at 0° C is 3·02 and the volume 100·0. Its density when completely molten at 1250° C. and at 1 atm. would be about 2·54; the volume would be 118·8.‡ Its compressibility would be about four times that of solid gabbro, which is probably of about the same compressibility as that of glass, viz., nearly ·0000026 per atmosphere. The pressure of 12,000 atmospheres would reduce the volume to 106·4; the density

* Quoted from a letter to the writer from Dr. Lane.
† C. Barus, Bull. 96, U. S. Geol. Surv., p. 83 ff., 1892.
‡ C. Barus, Bull. 103, U. S. Geol. Surv., p. 25 ff., 1893.

would become approximately 2·84. Barus has further shown that, so far as density is concerned, temperature and pressure, as these increase with depth on the normal earth gradients, nearly counterbalance each other's effects in glass, though the density should be somewhat increased with increase of depth.* It is not a violent assumption that the same be taken as true for rock-matter generally. The average density of the whole crust is thus nearly equal to the average density of its rocks, provided these are at surface temperature and pressure. The average specific gravity of the visible crust is not far from 2·75; but if the specific gravity of the whole crust were as high as 2·80, it might still float on the compressed gabbroid substratum.

The meagreness of existing experimental data will not allow that statements concerning crustal flotation can be other than in the conditional mood. It is certain that the relation between pressure and the volumetric diminution of a fluid cannot be linear for indefinitely great pressures. Yet the foregoing crude estimates clearly suggest the possibility that crustal foundering could not take place if the crust were even considerably thinner than it is to-day. When the difference in the compressibility of solid and liquid lava at great pressure is, in the future, once determined, it will first become possible really to test Kelvin's view as to the original cooling of the earth. The analogy of Barus's experiments raises the suspicion that the fragments of a foundering primal crust could sink only a comparatively few miles into the liquid interior. They would soon meet therein a level where their own density is matched by that of the more compressible fluid. Solidification by cooling would therefore not progress from the earth's center outwards, but would begin in a surface shell and slowly progress inwards.

Stresses within the crust.—It seems, accordingly, best to conceive of the earth as exteriorly composed of a thin solid shell characterized by tangential compression, a thicker underlying solid shell characterized by tangential tensions, and a liquid, gabbroid, perhaps highly viscous substratum of unknown thickness. This substratum is immensely elastic as to volume and is compressed by the weight of at least 25 miles of crust-rock. Beneath the surface shell of tangential compression the rate of secular cooling and contraction and the consequent tension increase from the level of no strain downwards all the way to the substratum. In his first paper Davison calculates that the average rending stress in the lower shell is, after a given time (if there be no relief by stretching or by cracking), four times the average compressive stress in the upper shell.

*C. Barus, Bull. 96, U. S. G. S., p. 61, 1892.

So long as folding or overthrusting of the shell of compression does not occur, the two shells are in physical continuity and are strongly bound together.

Secular accumulation of tensions and of cooling cracks.—It is generally agreed that, on the contraction theory of mountain-building, orogenic folding and crumpling is possible through the secular accumulation of compressive stresses in the outer shell. The crucial question has not yet been satisfactorily answered as to whether there may be similarly a secular accumulation of tension and of its effects in the inner shell of the crust. If the crust were a fluid of high though finite viscosity, the accumulation of tension would be impossible to any sensible extent; moreover, the weight of the crust overlying any subshell would necessarily close all cavities almost as fast as formed during the slow secular cooling. But the average rock of the crust is a true solid known to have a very low modulus of plasticity. Pfaff has, indeed, denied even the smallest measure of true plasticity to the average crust-rock, and his experiments seem to prove that massive rocks like granite, gneiss or gabbro would, at surface temperatures, not flow under the weight of even 25 miles of overlying rock.* They would rupture and shear, but the deformation would not reach the perfection of the molecular shearing implied in true flow.

A vertical crack due to cooling contraction would thus tend to be partly closed by shearing in of masses from its walls. The shear-planes would be inclined to the vertical. Each partial bridging of the crack makes further shearing and closing of the crack more and more difficult. A greater weight of crust would now be required since some support of the load is formed through the local meeting of the solid walls. The simple vertical stress becomes partially resolved into a complex network of oblique stresses tending to balance each other in the loci of lateral support. The portions of the crack occurring between these loci of support may remain open because of the diminished shearing stresses along the still gaping walls. It thus appears that, though all rocks at surface temperatures will rupture under the weight of less than 6 miles of crust, yet the complete closing of cracks at the same temperatures would not be expected even under the weight of a much greater thickness of crust. The depth of the shell ("zone") of fracture has been deduced from the crushing tests of stone and from the brilliant experiments of Adams and Nicolson on the deformation of marble enclosed in steel collars. The former tests evidently do not prove anything at all definite as to the pressures required to produce true plastic

*See Adams and Nicolson, Phil. Trans. Royal Soc. London, vol. cxcv, p. 367, 1901.

flow. The flow of marble under confinement has been produced under relatively low pressures, but this is a special phenomenon, the result of movement on gliding planes. A penknife and a few pounds of pressure will cause "flow" in a crystal of calcite. It is safe to say that similar conditions are not found in the average rock of the crust; if it flows at all the mechanism of the flow must be something entirely different.

Deformation within the shell of tension is not to be estimated simply by the ultimate strength of surface rock deformed in the laboratory. The experiments of Spring, Hallock and others show that the rigidity of a solid increases with pressures ranging up to those about twice that borne by our substratum.* This experimental law strengthens the belief that cavities may remain open in the shell of tension. On the other hand, the downward increase of temperature tends to lower the internal friction and thus to promote the closing of cavities. The pressure-gradient (1 atmosphere to about 3·7 meters of descent) is, however, steeper than the temperature gradient (1° C. to about 30 meters of descent) and it may well be that rigidity actually increases through the shell of tension down to its bottom layer, where, on account of the high temperature, the change of state, from solid to liquid, is approached.

A further indication that cavities may remain open in the shell of tension is indirect but none the less noteworthy. According to the assumption generally held by those adopting the contraction theory of mountain-building, the shell of tangential compression, free of load and unconfined as it is along its upper surface, can nevertheless for long periods of time endure without deformation a compressive stress perhaps several times greater than the weight of five miles of rock. It is the release of this pressure (which was *not* relieved by simple radial flow and thickening of the shell) that has led to the paroxysmal growth of a mountain-range. If the outer shell can long withstand such pressures, it is reasonable to believe that the material of most of the shell of tension is not perfectly plastic under the weight of overlying crust,—a pressure which is great but, in general, is only a fraction of the accumulated tangential stress of compression.

The same argument seems to apply also to the conceivable closing of cavities through the expansion of the compressed wall-rocks which tend to expand elastically into the opening vertical crack. For the reasons already outlined, this expansion must, under the conditions, take place, through most of the shell of tension, by shearing of mass against mass rather than by molecular flow. The induced partial closing of the cavity would, here again, tend to prevent further shearing and

* For references see review by C. F. Tolman, Jr., Journal of Geology, vol. vi, p. 323, 1898.

portions of the crack would remain unclosed. It is important to note that the shearing of mass against mass due to expansion along the walls is not additive to the effect of mass-shearing due to the dead weight of crust; the two kinds of deformation would progress simultaneously, and in proportion as masses moved under the one kind of stress, it would become more difficult for mass-shearing under the other kind of stress to take place. Only at the bottom of the shell of tension where the crust-matter is in the state intermediate between those of plastic solid and viscous fluid, would the cavities be closed entirely.

This part of the argument may now be summarized. On the whole it seems probable that a percentage of the whole tension developed in the lower shell through secular cooling remains, at any time previous to mountain-building, unrelieved by the stretching or cracking of that shell. At the level of zero-strain (which is above or not far below the bottom of the "shell of rock-fracture") cooling tension is at a minimum and resistance to stretching (shearing) is at a maximum. At the bottom of the crust the cooling tension is at a maximum but the resistance to stretching is at a minimum. The accumulation of tension and cooling cracks will therefore be at a maximum at some level near the middle of the shell of tension. The accumulation of compressive strains in the outer shell will be relieved to a certain extent by recrystallization leading to the development of denser minerals in the shell; but geological observation shows that, in a long period of time, enormous compressive stresses are alway stored until relieved by a more catastrophic process. The accumulation of the tensile stresses in the lower shell will be in some direct proportion to the degree in which relief is withheld in the shell of compression. Beneath a crust so diversely stressed, there is a compressed, elastic fluid which is ready, with relative suddenness and with prodigious force, to inject itself into the shell of tension as soon as there is any local relief of pressure or any breaking of the continuity of the shell.

The whole system is evidently in unstable equilibrium. If each shell were of uniform thickness and composition, and if there were no external forces acting on the system, it would be difficult to forecast when or where the strains could be relieved.

Injection of magma into the shell of tension.—But the earth's crust is not perfectly homogeneous; none of the shells is of perfectly uniform thickness; and, thirdly, there are other powerful forces acting on the material of the shell of tension besides those leading to stretching during the earth's contraction. Of special importance is the shearing of the whole crust in the torsional deformation incidental to the contraction, or in the torsion due to tidal stress. Slight as may be the effect

of a single tidal period, for example, it will, in certain lines appropriately oblique to the earth's equator, tend to wrench apart the crust even down through its viscous bottom layer. To such a powerful fluid as that composing the substratum, this viscous layer, suddenly sheared or broken, is relatively a solid mass; to the searching fluid a plane of shearing in the viscous layer is virtually a crack. Into that plane the tidal pulsations will pump the fluid, which instantly exerts its lateral hydrostatic and expansional pressures on a shell already prone to recoil because of the real though mild tension residual in the bottom of the shell. As the fluid thus works its way upward, it encounters rock which is increasingly more rigid and increasingly charged with accumulated tension and cooling cracks. In fact, if we conceive that the viscous bottom layer is once completely penetrated, it is easy to believe that the abyssal dike will be rapidly injected toward the top of the shell of tension. The shearing-in of the solid rock opposes the continued opening of the potential fissure, but this shearing, as the level of no strain is approached, becomes slower and slower and thus more and more powerless to check the rapidly acting wedge of expanding fluid.

The injection might conceivably (following Fisher's idea) be aided by the local removal of the viscous basement through the special attack of upward convection currents in the substratum; for it is clear that the injection is most difficult at its very beginning. Fisher has suggested that water-gas given off from the substratum when it is already injected into a downwardly-opening "chasm" may contribute force tending to widen the crack. However, such gas could not, on this hypothesis (the gas being dissolved in the magma according to Henry's law), segregate except by release of pressure. The release is a slow process. As a means of injection through the viscous layer the solution of magma and water-gas would be more effective than the compressed anhydrous magma, but their activities would be of the same kind. Fisher assumes that the magma is saturated under a pressure of 12,000 atmospheres. This implies that the more rapid the outflow of lava at a vent, the more imposing would be the explosive phenomena. It is obvious that this is not the case in nature. The exceedingly small amount of water in the lavas of fissure-eruptions and of the Hawaiian calderas seems, indeed, to show that the abyssal fluid is essentially anhydrous.* The water actually found in lava and that accompanying explosions of the Vesuvian type may be all or nearly all derived from the shell of rock-fracture. We conclude that it is wisest to find the positive penetrating force of the magma in its own elastic expan-

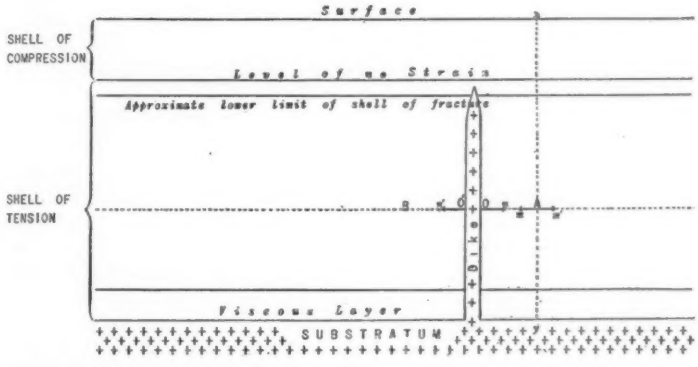
* Cf. J. D. Dana, Characteristics of Volcanoes, New York, 1891, p. 197.

sion operating wherever a line of diminished pressure is developed in the viscous layer.

It is also manifest that, if torsional or other shear is accompanied by vertical faulting, the abyssal injection will be still further facilitated.

Relief of tensions through abyssal injection.—Whether the foregoing hypothesis be correct in details or not, there is no doubt that abyssally-injected dikes have actually been fed from the gabbroid substratum upward to the vents of fissure eruption. Granting, secondly, that there are cooling cracks and considerable unrelieved tensions in the crust, as already

1



described, consequences of fundamental importance seem to be deducible.

On account of the strong compression at the earth's surface the magma of the abyssally-injected dikes will not in most cases reach the surface. The act of injection produces a great change in the conditions of equilibrium in the shell of tension and therewith in the whole crust.

Let figure 1 represent a sectional view of the system after injection, the earth's curvature being neglected and the dike being shown in cross-section. The level of no strain is represented as about five miles below the surface—a depth somewhat greater than the maximum calculated by Fisher.—The principle of the following argument is not affected if the depth should be a fraction of one mile or as much as six or possibly more miles.

"A" is a particle of the crust within the solid shell of tension. In the stretching of the shell such a particle must move not only radially toward the earth's center but tangentially as well. If the shell is homogeneous, the weight of the overlying crust will tend to shear the particle indifferently toward

m or m' or toward any one of an infinite number of other points lying in the circumference of a horizontal circle circumscribed about the vertical passing through A and with radius Am. The shear-movement of particle A is, however, strictly controlled in direction so soon as a liquid dike is injected. At the level of A the point O in the wall of such a dike bears a combined hydrostatic and elastic pressure from the magma. The former pressure is sensibly equal to the weight of the column of rock Ax; the maximum elastic pressure equals the weight of the column Ay. The total of these pressures, represented by the line On, is equal to the oppositely directed force O$'n'$ on the other wall of the dike. On is not only a positive force compressing the matter between O and A; it is also, and yet more significantly, a *directive* force which determines the direction in which particle A must move as it is affected by the tensional pull of secular cooling and by shear during the compressive extension (stretching) of the shell of tension. As long as the dike remains fluid, particle A will move in the direction of the arrow Am'. The condensation of matter, which, before the dike-injection, had been only potential (being due to the accumulation of tensions and cracks in the shell), now becomes actual. As particle A is forced toward m', a neighboring particle, A_1 on the same level and to the right hand of A, is similarly brought under pressure and moved in the direction of the arrow Am'. A_1 communicates its motion to A_2 and so on. The pressure at O is thus felt within the shell as far away from the dike as the relief of the accumulated tension and the closing of cooling cracks can take place.

The movement of particles A, A_1, A_2, etc., is analogous to the work of a railway engine pushing down a train of cars which had been standing on a grade with each coupling pin at full length because of the grade. Buffer meets buffer, communicating the pressure of the engine. If the train had been nicely poised, just ready to move before the pressure was applied, and if the grade were indefinitely long, a small pressure would set in motion a train of indefinite length. The analogy is not perfect since the creep of the particles in the shell of tension is not free but is controlled by internal friction and by the strong adhesion between the shells of compression and tension. Nevertheless, it is not difficult to believe that lateral creep would be set up at a distance perhaps several times the thickness of the whole crust.

Since the conditions are precisely the same for particles B, B_1 (to the left of B), B_2, etc., there will be similar creep on the side of the dike opposite to A in the direction of the arrow O$'n'$. The dike is thereby widened. The correlative injection of new fluid magma makes this new system of

motions self-perpetuating until the attainable relief of tensions and closure of cracks is accomplished.

Thereafter, two possibilities are open. The now much widened dike may have lost sufficient heat to solidify. The system of directed creeps or lateral movements will then be exchanged for an undirected compressive extension similar to that which prevailed before the injection. Or, if the dike remains fluid, it will cause an indefinite continuance of lateral creep keeping pace with the differential cooling contractions in the shell of tension. In the former case, the injection of a second and of yet later dikes is possible, and their net effects, provided these dikes are elongated in the same general earth-zone,* are additive to those of the first dike. Tidal or other torsion may locate such a zone of special igneous injection.

Down-warping of the surface as a result of abyssal injection.—We have seen that lateral creep will be fastest somewhere near the middle level of the shell of tension, because it is there that the defect of condensation of matter, shown in cooling crack and in residual tension, is at a maximum. The ensuing condensation of matter in the shell is at a maximum in the immediate vicinity of the zone of injection and gradually decreases to each side of the zone. Since the two shells are still solidly knit together, the enforced creep of matter to right and left of the great dikes involves a strong downward pull exerted on the shell of compression. A down-warp of the earth's surface is thus established. The initial down-warp is of length, breadth and depth dependent on the magnitude of the injected body or bodies. Where the injection is on a large scale the down-warp may be of geosynclinal dimensions.

The down-warping implies, however, that the former nice balance of stresses in the zone of compression is destroyed. Those stresses will henceforth tend directly to increase the down-warp. Sedimentation within the down-warp increases the weight on the creeping material of the shell of tension, which is also now beginning to feel a small downward pressure, a component of the total thrust of the now bent shell of compression. The down-warping of the surface may thus gradually increase even after all magmatic injections in the zone of tension have frozen solid.

The conditions for mountain-building.—The shell of compression is now weakened, as experimentally illustrated by Willis in his memoir on mountain-building.† The weakening is most felt in the two lines where the down-warped surface parts from the spheroidal curve of the earth. If sediment

* Throughout this paper the word "zone" is used in its proper mathematical sense of a "portion of the surface of a sphere included between two parallel planes."—As prevailingly defined, the "zone of fracture" in the earth may here be profitably called the "shell of fracture."

† B. Willis, 13th Annual Report, United States Geological Survey, p. 217, 1893.

accumulates to the depth of many thousands of feet in a geosynclinal, the material of the original shell of compression is softened by the rising of the isogeotherms, while the strength of the new shell of compression occupied by the sediments is low because of the poor consolidation of this new formation. For a double reason, therefore, a broad zone of weakness in the shell of compression is developed over the zone of igneous injection. Sooner or later the secular accumulation of compressive stresses will express itself in the orogenic collapse of the shell; the building of an alpine mountain range is begun.

The most serious objection to the contraction theory—that the earth's amount of contraction is insufficient for the orogenic

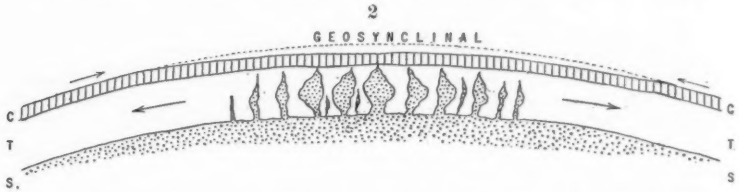


FIG. 2.—Diagrammatic cross-section showing the relation of a geosynclinal to a zone of abyssal injection. C (vertical lines)—shell of tangential compression; T (blank)—shell of tangential tension; S (stippled)—substratum. The smaller arrows show the direction of compressive stresses; the larger arrows show direction of rock-creep in the shell of tension. The original position of the surface before the geosynclinal down-warping is shown by the dotted line. Some of the injected bodies of magma are represented as of batholithic size; the same amount of rock-creep in the shell of tension and of down-warping of the surface would have been produced by the injection of smaller bodies, more numerous and also closely spaced in the zone of injection. Scale: about 65 miles to one inch; the curvature of the earth's surface is exaggerated about ten times.

work actually done through geological time—has been founded on mathematical deductions. As with the so-called demonstration of the earth's extreme rigidity, the deductions are no stronger than the assumptions as to the interior economy of the globe. If the earth's vast nucleus is gaseous, as seems so highly probable, the larger part of the earth may be cooling and contracting according to different laws from those hitherto accepted as a basis for calculation.* For example, the contraction of the nucleus may follow a modified "law of Charles"; secondly, we should expect that, with cooling, there will be, within the globe, the liquefaction of gas as well as the solidification of liquid—both changes of state possibly being accompanied with special diminutions of volume. The phenomenon of earth-contraction may thus be much more complicated than it has been assumed to be, but the added complications would probably be favorable to the contraction theory of crustal deformation.

* Cf. S. Arrhenius, Geol. Fören. Stockholm Förhandlingar, xxii, p. 395.

Expansion of the earth's outer shell as a factor in mountain-building.—But there is good reason to believe that the contraction theory, as usually stated, carries only half a truth. Both advocates and opponents of the theory have generally spoken of the collapsing surface shell as of nearly constant circumference since the time of original crustification, except for the amount of overthrust and overfold represented in folded and faulted regions. This shell is, indeed, conceived as itself having slightly shrunk through loss of heat during geological time, little or no emphasis being placed on those agencies which tend to counterbalance this shrinking and even

3

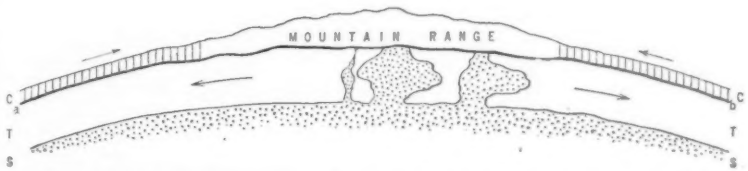


FIG. 3.—Diagrammatic cross-section showing relation of mountain-building to simultaneous and subsequent abyssal injection of magna. Scale and symbols the same as in figure 2. *a–b* (heavy line): the surface on which the shell of compression shears over the shell of tension in the orogenic thrust-movement. Two large batholiths of slightly different ages are represented; the mountain-building is supposed to have been just completed. The igneous bodies injected and crystallized before the epoch of mountain-building are not shown.

produce a net expansion of the shell. Nevertheless, it seems highly probable that the original shell has actually grown larger instead of remaining sensibly of constant circumference, and that a part, perhaps the greater part, of the circumferential shortening observed in the world's mountain ranges is due to this fact.

The outer skin of the earth, including its overthrust portions, may grow areally larger according to two different processes.

a. Local cavities produced in the shell of compression by crustal readjustments may be rapidly filled with magma from beneath or, more slowly, with vein matter deposited from circulating waters. True magmatic injections, such as dikes, laccoliths, "chonoliths,"* etc., and possibly a percentage of batholithic irruptions represent just so much additional matter squeezed into the shell. These wedges when solidified, like all the countless mineral veins, aid in transmitting and increasing the thrusts affecting the shell as it collapses on the shrinking "nucleus" of the earth. This view has been clearly

* Defined in Journal of Geology, vol. xiii, p. 498, 1905.

enforced and illustrated by Shaler* and must be regarded as embodying a true condition of crustal deformation.

b. Still more important is the consideration that the shell of compression is the home of those metasomatic changes in rocks that lead to expansion of volume. One of the most striking results of Van Hise's researches in metamorphism is his conclusion that in this shell the average effect of hydration, carbonation and oxidation is to cause such expansion on a surprisingly large scale.† For example, if a gabbro were completely altered according to the normal reactions in the "katamorphic zone" (which, in position and depth, is very nearly identical with our shell of compression), there would be a volumetric increment of at least 25 per cent. If the entire shell were gabbroid, and if but 4 per cent of its substance had, in post-Archean time, been similarly hydrated and carbonatized, the volumetric increase would be about sufficient to explain all of the observed overthrusting and overfolding of post-Archean mountain-ranges. The rocks of the continental plateaus are, however, largely composed of quartz and orthoclase, two minerals which do not show volumetric expansion in their alteration. The part of the shell underlying the deep ocean-basins is of unknown composition, but pendulum observations and other general considerations suggest that this greater part of the shell is basaltic, and has, in general, never been exposed to subaerial erosion. Under the deep seas especially the maximum amount of metasomatic expansion and the maximum accumulation of corresponding compressive stress might, accordingly, be expected. It is conceivably to this cause that we may refer the fact that the thrust of mountain-building has, throughout the world, been chiefly from the ocean toward the land. In any case the average result of the alteration of rocks, whether by cold descending waters or by hot ascending waters, or by water trapped within the shell, and with all allowance made for solution of mineral matter which is thus removed to the oceans, is to bring about expansion of volume within the shell. This expansion must be accompanied by tremendously energetic compressive stresses; the process is homologous to the hydration of a bed of anhydrite. Since these chemical reactions take place mainly along more or less vertical cracks, fault-planes, joints, etc., the expansional force will be chiefly directed in planes parallel to the earth's surface. The relief of the strains through simple vertical expansion is resisted by the strength of the unaltered rock lying between the vertical zones of chemical alteration.

* N. S. Shaler, Science, xi, p. 280, 1888.

† C. R. Van Hise, Treatise on Metamorphism, Monograph xlvii, U. S. Geol. Surv., pp. 631 ff.

It is manifestly impossible to test these conceptions quantitatively, thus comparing their calculated effects with the known needs of the orogenic problem. Yet they are worthy of attention as valuable adjuncts to the thermal-contraction theory of mountains. "It may in the end turn out that mountains are the result of a tolerably complicated series of causations, in which secular refrigeration of the earth, the transfer of weight by the operations of erosion and deposition, and the subterranean migrations of matter, all take a part."* The energy for crustal deformation may thus lie in the combination of two immense forces—the force involved in massive readjustments within an entire cooling planet, and the force involved in the molecular readjustments among its recrystallizing ultimate particles. Other causes, such as the torsional shears expected in a planet suffering a progressive change in its rate of rotation, may further supplement those causes which have here been briefly noted as seemingly the most important.

Renewed abyssal injection following mountain-building: development of batholiths.—The extent to which shortening of the transverse axes of the world's mountain ranges has occurred shows that each orogenic revolution has been accompanied by a wholesale shearing of the shell of compression over the shell of tension. The surface of shear is probably not far from the level of no strain.

One effect of the shearing, faulting and crumpling may be to squeeze small bodies of magma up into the upper shell. But the grandest results of igneous intrusion would be felt in the shell of tension. The instant that the two shells are sheared asunder, the tensions that have been accumulated because of the solid continuity of the two shells, and are still residual after the preceding injection of magma, are relieved. The shell of tension is henceforth free to contract on itself. A fluid dike now injected into this shell or a dike injected previous to the shearing but still fluid, would tend, according to the process already described, and especially because of the energetic, spontaneous retreat of the country-rock on either side, to enlarge itself. Opposed to the active retreat and enforced creep of the solid rock of the shell away from the middle plane of the dike, and thus to the ready contraction of the shell, is the friction developed at the surface of shear. Since the shear is directed tangentially with respect to the curve of the earth, the strength of the friction is measured directly by the weight of the shell above the shear-surface. At the upper extremity of a dike which reaches exactly to the shear-surface, the hydrostatic pressure exerted on the dike-wall is somewhat greater than the weight of the shell above the shear-surface. The magma has, in addition, the live energy

*N. S. Shaler, op. cit., p. 281.

of elastic expansion measured by the compression due to the weight of the whole shell of tension. The net effect of these forces is to permit of the contraction of the shell already prone to movement on account of the sudden relief of tension, and to cause a widening of the dike which may assume batholithic proportions. It is important to note that the recoil within the shell due to the relief of tensions will characterize the whole of the area over which the shells of tension and compression have been sheared apart; this area may be several thousand miles in diameter. The piling up of the mountain-mass above would also cause an enhanced rapidity or lateral flow in the shell of tension and likewise widen the magmatic chamber. Injection into the mountain-rocks themselves would only be possible where there is local relief of compression in the now heterogeneous, unequally squeezed, and writhing mass. Since, in the nature of the case, compression generally dominates, igneous injection will, in this period, afford but small geological bodies as constituents of the range.

At the mountain-roots below the surface of shear there are one or more great bodies of gabbroid magma specially injected as a result of mountain-building. Through the physical and chemical activity of this magma the acid igneous stocks and batholiths so characteristic of mountain-range of the alpine type, may possibly be explained by the assimilation-differentiation theory.* The cycle of changes which have affected our initial system (compression-shell, tension-shell and fluid substratum) thus began with igneous intrusion and closes with igneous intrusion. On account of the relief of compressive strains in the superficial shell, the latest and probably greatest intrusive bodies are free locally to flux or stope their way well into the shell of fracture.

With certain assumptions, several authorities have calculated that the level of no strain has always lain at a depth no greater, or but very little greater, than the bottom of the shell in which rocks can readily fracture.† In rising through the shell of tension the gabbroid magma has expanded so much and attained such low viscosity that down-stoping and abyssal assimilation of shattered roof-blocks is now possible. To the differentiation of the compound magma so produced, the granitic batholiths and stocks, many injected laccoliths, "chonoliths" and dikes, as also many lavas more acid than gabbro, have been attributed. There are reasons for believing that magmatic stoping is much more potent than fluxing assimilation on main contacts. If granites, etc., are really secondary after the manner indicated, they can only be formed in the shell of fracture and on the large scale where the tangential

* See R. A. Daly, this Journal, vol. xv, 1903, p. 269; vol. xvi, 1903, p. 107; vol. xx, 1905, p. 185.

† The limits of the shell of ready fracture, as conceived by Van Hise, are shown in Fig. 1.

compression of the superficial shell is relieved. Otherwise stoping is impossible, for a large magma chamber could not remain open in the zone of unrelieved compression. Granites and allied rocks are, by this hypothesis, primarily mountain-rocks. That this is the fact hardly needs statement.

Vulcanism as a result of mountain-building.—By the inevitable settling-down and block-faulting which follow the orogenic paroxysm, both primary basaltic lava and secondary lavas of indefinite variety may be squeezed out to the surface. Volcanic activity is not, by the hypothesis, necessarily confined to zones of intense mountain-building, but should be specially developed in those zones. The volcanic problem and the orogenic problem are in general both related to the same necessity of understanding the mechanical rearrangements when, for any reason, fluid material from the substratum is injected into the shell of tension.

Summary.

Postulates.—The assumptions on which the foregoing hypothesis has been based are the following:

a. A cooling earth superficially composed of a relatively thin crust overlying a fluid gabbroid substratum of unknown thickness.

b. The substratum so much compressed by the weight of the crust as to be probably able to float the crust.

c. Through differential cooling contraction the development of a level of no strain in the crust not far from the bottom surface of the shell of rock-fracture.

d. The accumulation of pressure in the shell of compression and the simultaneous accumulation of cooling cracks and of some of the powerful tension unrelieved in the shell below the level of zero-strain.

e. A steady or recurrent dislocation of the shell of tension permitting of the forceful injection of the fluid substratum to which even the viscous layer of the shell acts as a relatively solid mass at the moment of dislocation. This dislocation has been referred to the tidal torsion of the earth's crust, but sub-equatorial torsion on the tetrahedral theory of the earth, or crustal deformation due to the play of other cosmical forces or of forces induced by the heterogeneity of the crust, may similarly cause dislocation in the shell of tension.

Conclusions.—1. The abyssal injection involves condensation of the matter in the shell of tension. Cracks are closed and much of the accumulated tension is relieved by an enforced creep of matter away from the injected body. So long as the body remains fluid the stretching of this shell due to continued cooling of the earth is accomplished by creep of matter in the same

directions. The amount of creep is at a maximum above the zone of injection and decreases to a minimum at certain distances to right and left of the middle line of the zone.

2. This lateral creep induces a down-warp of the earth's surface immediately overlying the zone of condensation. The resulting geosynclinal may be the seat of prolonged sedimentation. If so, the weight of the sediment itself tends to increase the lateral creep in the shell of tension and the down-warp slowly deepens.

3. The shell of compression is already weakened at the angles of down-warp; it is further weakened by the sedimentary blanket which, comparatively little resistant itself, causes a softening of its basement through a rising of the isogeotherms. When the filling of the geosynclinal has sufficiently thickened, the shell of compression, owing to its secular accumulation of stresses (which are intensified by metasomatic changes in the shell), begins to collapse. Mountainous forms and structures result.

4. The complete shearing apart of the shells of compression and tension during the orogenic revolution releases the tensions still unrelieved in the underlying shell. Abyssal injection on a large scale is thus initiated or continued in the shell of tension. The relief of compressive stresses in the act of building the mountains first occasions the possibility of magmatic stoping and thus of the extensive assimilation of schists and sediments by the primal gabbroid magma. The differentiation of the compound magmas of assimilation may explain the batholithic central granites, etc. of mountain ranges, along with their satellitic stocks, injected bodies and volcanic outflows.

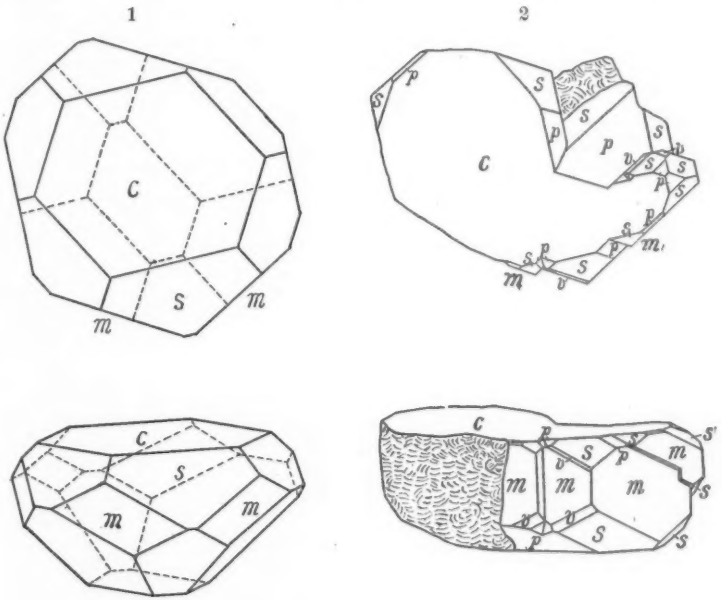
5. The regional warpings of the earth's crust may be partly at least referred to the varying strengths of abyssal injections from a fluid substratum.

6. The location and alignment of mountain ranges, the location and elongation of geosynclinals, the final development of igneous batholiths and satellitic injections, are all interdependent and related to *special* zones of powerful abyssal injections from the substratum. These zones are, in the large, located by cosmical stresses affecting the earth along special azimuthal lines.

7. Mountain building causes relief of compressive stresses in the superficial shell. The surface outflow of magma either secondary or directly derived from the substratum may therefore be specially pronounced after an orogenic revolution. In general, the theory of vulcanism is also fundamentally affected by the doctrine of the shell of tensions which are not entirely relieved by the compressive extension of that shell.

ART. XIX.—*Some Interesting Beryl Crystals and their Associations;* by W. E. FORD.

THE beryl crystals commonly found in pegmatite veins are prismatic in habit, consisting of a simple combination of the prism of the first order, *m*, with the base, *c*, and as a rule are only semi-transparent, and of a green color. It is the chief purpose of this article to describe several striking exceptions to

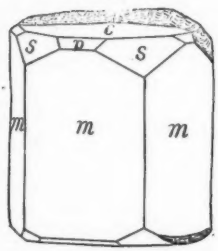


this general rule, and to point out some interesting similarities in crystal habit, color and association shown by a series of beryl crystals from a number of different localities, all of which are noted for the occurrence of variously colored tourmalines of the lithia variety and of gem quality.

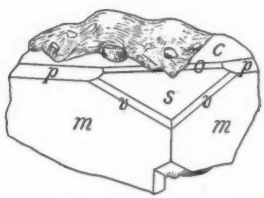
The pegmatite deposits of San Diego Co., California, which have become famous on account of their beautiful tourmalines, have lately furnished some beryl crystals of an unusual habit and uncommon color. Figure 1 is of a crystal from the deposit at Mesa Grande, while figures 2 and 3 are of crystals from the locality of Pala. The short prism which they show, especially in figures 1 and 2, together with the large and

prominent development of the pyramid of the second order s $(11\bar{2}1)$, give them a habit of crystallization very different from that usually shown by beryl. The crystal represented by figure 2 also shows smaller replacements by faces of the pyramid of the first order p $(10\bar{1}1)$ with an occasional face of the dihexagonal pyramid v $(21\bar{3}1)$. It is further complicated by several reëntrant angles caused by a repetition of the faces due to parallel growth. The figures are drawn to show as nearly as possible the development of the faces in their true proportions, figure 1 being about natural size while figures 2 and 3 are one half natural size. The crystals are transparent and of a beautiful light rose-pink color: their extraordinary color combined with their unusual habit of crystallization

3



4

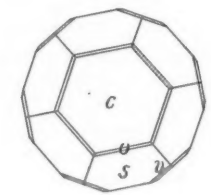


make them especially noteworthy. Figure 1 is of a crystal loaned for study by Mr. Ernest Schernikow of New York and which has since come into the possession of the Brush Collection, while the crystals represented by figures 2 and 3 are in the Tiffany Gem Collection in the American Museum of Natural History, New York.

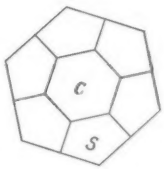
Figures 4, 5 and 6 are of beryl crystals showing interesting similarities in habit and association with those just described, but from other localities. Figure 4 represents an incomplete crystal found at Mt. Mica, Paris, Maine, now in the mineral collection of the American Museum of Natural History in New York. It shows a short development of the prism m with prominent faces of the second order pyramid s; also small replacements of another pyramid of the second order o $(11\bar{2}2)$, of the pyramid of the first order p, and of the dihexagonal pyramid v $(21\bar{3}1)$. The crystal is transparent and colorless like pure quartz, and attached to it are plates of lepidolite. Figure 5 is likewise of a colorless crystal from Mt. Mica belonging to the Brush Collection, nearly complete, quite symmetrical in development and about 15^{mm} in diameter. It is characterized by small faces of the prism m and a large development of the pyramid s, while o and v were observed as

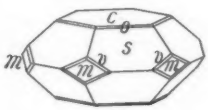
small truncations. Figure 6 is of a crystal in the Brush Collection from the famous tourmaline locality of Haddam Neck which corresponds to these other crystals in having the pyramid of the second order unusually prominent, although on this crystal the prism faces are large and well developed. This crystal is transparent and has a very pale pink color. Several other light-colored crystals from Haddam Neck showing a development of faces similar to that of figure 6 are in the mineral collection of the American Museum of Natural History. One very large one, donated to the Museum by Mr. Ernest Schernikow, measures 18 inches in length by 1 foot in diameter. It is doubly terminated, but so attached that only a portion of its faces are developed.

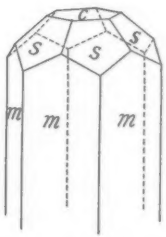
5



6







Pink beryls were formerly found at Goshen, Massachusetts, associated with tourmalines of light to dark green color, and were given the name of goshenite by Shepard.* Specimens of beryl from this locality in the Yale College Collection show only the forms of the prism *m* and the base *c*. Transparent, colorless and pink beryls are also found in the Island of Elba associated with variously colored gem varieties of tourmaline. A specimen of pink beryl in the Brush Collection from Elba shows a short prismatic development terminated only by the base. Vom Rath† describes the Elba beryls as being usually transparent and frequently of a light pink color, and although light green and blue crystals occur there as well, they are

* A Treatise on Mineralogy, third edition, 1852, p 229.
† Z. d. d. Ges. xxii, 661.

often only semi-transparent. These crystals are described as having generally a prismatic habit, but he mentions several instances where they are markedly tabular in development.

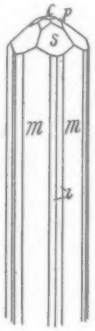
It is interesting to note the striking similarity in habit, color and association of beryl crystals from these different localities. Many of them are of an unusual crystal habit for beryl, frequently being short prismatic, at times even tabular parallel to the base, and occasionally are highly modified. They are also of unusual color, some of them colorless, others of a light tone of pink, quite distinct from the green or blue-green shades commonly shown by beryl. All of them also were found in pegmatite deposits associated with variously colored green and pink tourmalines of gem quality. Such coincidences of association of beryl crystal of unusual habit and color with tourmaline crystals of light colors and gem quality are interesting and suggestive. To the writer's knowledge, the ordinary green beryl, showing a simple combination of prism and base commonly found in pegmatite veins, occurs rarely at the localities which furnish gem tourmalines. It would seem not at all improbable that the conditions favorable to the formation of tourmalines of gem quality were likewise favorable to the formation of these beryl crystals of unusual color and habit.

The factors which control such matters as mineral occurrence and association are undoubtedly extremely complex, being both physical and chemical in their nature. It would seem probable however, if this association which has been noted is anything but accidental in character, that some chemical similarities might be found to exist between these types of tourmaline and beryl. It has been noted that gem tourmalines are usually characterized by containing about twice as much of the alkali oxides as the ordinary varieties, Li_2O being practically only found in the gem material. The occurrence of small amounts of alkalies, usually Na_2O and Cs_2O, have been frequently noted also in beryl. It was thought therefore that any chemical similarity between the gem tourmalines and the pink or colorless beryls would be in the presence in each of unusual amounts of the alkali oxides. Quantitative tests for alkalies were therefore made on two different beryls, the first being pink material from Mesa Grande, the same as that of the crystal illustrated in figure 1, while the second was a pale pink opaque crystal in the Brush Collection from Haddam Neck. Both of them showed considerable amounts of alkalies, the Mesa Grande material yielding about 3·00 per cent and that from Haddam Neck about 5·00 per cent of mixed alkali oxides. From both of them strong tests for cæsium were obtained by use of the spectroscope. In this

connection an analysis* by H. L. Wells of a clear and colorless beryl found associated with gem tourmalines at Hebron, Maine, might be quoted, which yielded Na_2O, 1·13; Li_2O, 1·60, and Cs_2O, 3·60. These few instances would seem to indicate that these unusually colored beryls are liable to contain several per cent of alkalies, cæsium being characteristically present. Their association with those tourmaline crystals, which likewise contain unusual amounts of alkalies, can hardly be considered entirely accidental, and consequently in this fact of chemical similarity we probably find one of the conditions which influence the association of this type of beryl crystals with the gem tourmalines.

Figure 7 is of a transparent green crystal (aquamarine) in the Brush Collection from the Mack Mine, San Diego Co., California, and is introduced here chiefly for the sake of contrasting it with the tabular type from the same general locality shown in figure 2, the two crystals representing the opposite extremes of development. The crystal is represented in the figure in its true proportions, except that its length parallel to the vertical axis should be four times as great as is shown. The length of the crystal is approximately fifteen times as great as its diameter, the actual dimensions being 60×4^{mm}. The faces on the crystal are the prism of the first order m, the dihexagonal prism i $(21\bar{3}0)$, the pyramid of the second order s and the pyramid of the first order p, with the basal plane c, and are developed with almost ideal symmetry.

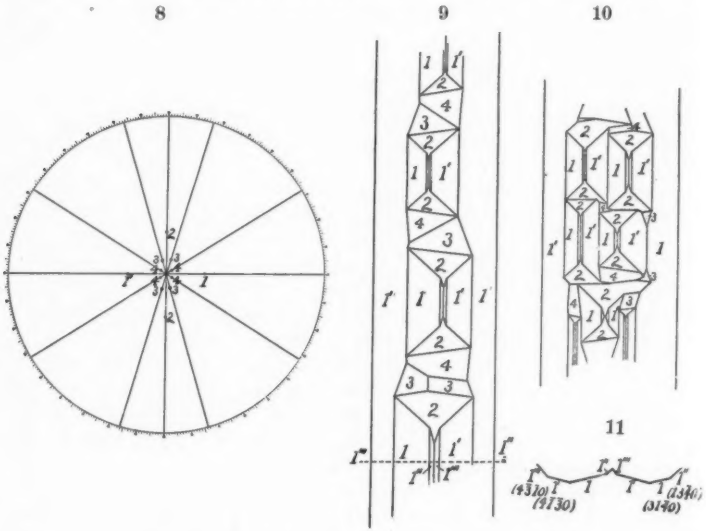
7



There are also in the Brush Collection two perfectly transparent and yellow colored beryl crystals from Ramona, San Diego Co., which show remarkable etchings: These are in the form of depressions arranged singly in line, figure 9, or in groups, figure 10, in the positions which would naturally be occupied by faces of the prism m. The prism m, however, does not appear on the crystals, the groups of pits corresponding in position to adjacent m faces being separated from each other by a dihexagonal prism. Measurements of a series of the faces forming the pits were made on a two-circle goniometer and the averages of the results obtained were used to plot the positions of the faces on a gnomonic projection, figure 8, the plane of projection being taken as parallel to m $(10\bar{1}0)$. From this projection figures 9 and 10 were made, which show the character and arrangement of the etched pits drawn in orthographic projection upon a plane parallel to m. The faces were all

* Dana's Sys. Min., p. 407.

rounded and gave only approximate measurements, consequently no definite symbols can be assigned to them. The dihexagonal prism designated as *1*, which appears on the crystals and forms prominent faces in the pits, is close to a form having $(31\bar{4}0)$ as its symbol. The faces in the pits marked *1* are the same as the right hand prism face $(31\bar{4}0)$, also marked *1*, and reflect the light simultaneously with it; and those marked *1′* reflect together with the left hand prism face, $(41\bar{3}0)$, designated as *1′*. The bottoms of the pits are usually occupied by two small faces making a very acute angle with one another which correspond to the two prism faces designated as *1″* and *1‴*, figure 9, which lie to the right and left



beyond those marked *1* and *1′*. Figure 11, which is a horizontal section along the dotted line in figure 9, illustrates the relations existing between the faces of the dihexagonal prism and the corresponding faces found in the pits. The pyramid of the first order, designated as *2*, which always forms the upper and lower faces of the pits, approximates in its position to $(13\cdot0\cdot\bar{1}3\cdot2)$. In addition to these faces the etchings show two other forms, *3* and *4*, which in their positions correspond to the faces of dihexagonal pyramids. They are of vicinal character, falling very close to the prism face *m*, as is shown in the gnomonic projection, one averaging only 4° 57′ and the other 2° 13′ from *m*. Because of the uncertainty of the meas-

urements due to the vicinal character of the faces, exact symbols cannot be assigned to these forms. In some places the pits form a single line down the length of the crystal, not encroaching at all on the faces of the dihexagonal prism at the sides, as shown in figure 9. More generally they are in two or more parallel and adjacent lines and interlock with each other in a very complicated manner, as shown in figure 10. The pits average 2^{mm} by $1{\cdot}5^{mm}$ in size. The crystals show a tendency to taper at the ends on account of the etching and rounding of the prism faces.

Acknowledgment should be made of the courtesy of Mr. Ernest Schernikow of New York and of Messrs. H. C. Bumpus and L. P. Gratacap of the American Museum of Natural History in New York, for furnishing for study the crystals illustrated in figures 1 to 4. The writer also gratefully acknowledges the frequent help, through criticism and suggestion, of Prof. S. L. Penfield during the preparation of this article.

Mineralogical Laboratory of the Sheffield Scientific School
of Yale University, New Haven, Conn., June, 1906.

Art. XX.—*Schistosity by Crystallization. A Qualitative Proof;* by Fred. Eugene Wright.

In the general theory of the metamorphism of rocks, pressure, especially stress applied in one direction, has long been considered an important factor; and in recent years sufficient evidence has been accumulated by geologists from observations in the field to demonstrate practically its influence on the textures of rocks during their formation. Investigations of the behavior of a body or chemical system under stress have also been made by chemists and physicists, and fundamental laws of equilibrium deduced therefrom which have a direct bearing on the broader problems of metamorphism.

Le Chatelier* discovered a number of years ago, that in a chemical system "any change in its factors of equilibrium from outside is followed by a reverse change within the system." At constant temperatures, therefore, an increase of external pressure tends to produce those changes which are attended by diminution of volume. In the words of Bancroft,† "the system in equilibrium tends to return to equilibrium by elimination of the disturbing element." Most solids dissolve with decrease in volume: when this is the case, the solubility is increased. Riecke and also Hambuechen‡ have proved experimentally an important deduction from this general law, that a body under unequal strain dissolves most rapidly along the line of greatest stress.

In accord with this law of physical chemistry, Van Hise,§ reasoning from the standpoint of geology, has shown that in the deep-seated zone or zone of anamorphism "the deformation in connection with mass mechanical action is mainly accomplished not by mechanical subdivision but by the chemical action of recrystallization;" that "under strains with a stress difference an exceedingly small amount of water at the high temperature is capable of dissolving particles of substance under the greatest stress and depositing them along lines of less resistance, the movement of the solution being slight and

* Comptes Rendus, xcix, 786, 1884; quoted in W. D. Bancroft's "The Phase Rule," Ithaca, 1897, p. 4. Van't Hoff has also derived the same law from the second principle of thermodynamics and expressed it in mathematical terms. Studien zur Chemischen Dynamik, Van't Hoff and Cohen, p. 223.

† "The Phase Rule," Ithaca, 1897, p. 4.

‡ Riecke, E., Nachr. v. d. K. Ges. d. Wissensch. zu Göttingen, Math.-phys. Klasse 1894, iv, 278–284; Hambuechen, C., "An Experimental Study of the Corrosion of Iron under Different Conditions," Bull. Univ. of Wisconsin, No. 42, 1900, p. 255.

§ "Metamorphism of Rocks and Rock Flowage," Bull. Geol. Soc. America, vol. 9, May, 1898; also "Treatise on Metamorphism," U. S. Geol. Survey, Mon. 47, Chap. vii: viii (1904).

the quantity of substance in the solution at one time being extremely small." Through the superheated water as a medium, adjustment by solution and deposition goes on continuously during the deformation. Under such conditions minerals like the micas and amphiboles, which have a tendency to grow most rapidly in one direction, develop with their longer axes in the direction of least resistance, perpendicular to the line of greatest stress; and the texture of the resultant rock will be characterized by a parallel arrangement of its mineral components.

Since in such metamorphic rocks the recrystallized silicates belong chiefly to the micas, amphiboles and feldspars, all of which cleave well, the cleavage of these rocks is due in large part to the cleavage of their components. In short, the textures observed in metamorphic rocks of this type are characterized by a definite orientation of mineral components recrystallized at high temperatures under unequal stresses.*

Becke† has applied the name Krystallizationsschieferung to this process of recrystallization under stress and has reached conclusions similar to those of Van Hise outlined above.

A recent investigation by G. F. Becker and A. L. Day‡ on the development of crystals under stress shows that although crystals are able to grow in a given direction in spite of a counteracting force, their growth in the plane normal to the pressure is vastly greater, the proportion being about 1 to 1000 or still larger. In their experiments, alum crystals were used which are isometric and which have, therefore, no peculiar direction of elongation. Had substances been tried which crystallize in prismatic or tabular shapes, it is probable that there, also, the direction of most rapid crystal growth would have coincided with the direction of least resistance normal to the active stress, as in the experiments below.

In the Geophysical Laboratory of the Carnegie Institution, several experiments were performed in imitation of this process of nature, and results were obtained which roughly verified the preceding theoretical deductions. The problem which confronted us was to produce crystallization from solution under strain. Purely aqueous solutions could not be used, since in them hydrostatic conditions obtain and stress differences are not possible. A glass, however, from a physico-

* The arguments given in brief in this paragraph are essentially those of Van Hise developed *in extenso* in his monograph, *loc. cit.*

† Becke, F., Uber Mineralbestand und Struktur der Krist. Schiefer; Sitzunsber. Wiener Akad., 7 Mai, 1903. This paper was unfortunately not available to the writer. A brief statement of his conclusions, however, is given by U. Grubemann in "Die Kristallinen Schiefer," i, (1904).

‡ "The Linear Force of Growing Crystals," Proc. Wash. Acad. Sci., vii, 283–288, 1905.

chemical standpoint is an undercooled liquid, and in it the viscosity or internal friction at temperatures at which crystallization may begin is sufficiently great to permit application of unequal stresses. Certain glasses, as those from wollastonite, diopside, anorthite and other minerals, crystallize at temperatures far below the melting point of the mineral, and while still in a state of fair rigidity.

These minerals are, moreover, either prismatic or tabular in habit and possess, therefore, a decided inclination to grow more rapidly in one direction than in another. If made to crystallize under unequal stress, they will, in consequence, tend to develop most rapidly in the direction of least resistance and their favored axis or plane of growth (prismatic or pinacoidal) will be normal to the active stress; while the resultant texture will be comparable to those produced by the recrystallization of a rock under stress.

In our experiments about 50 grams of each of the above minerals were first melted separately in a Fletcher furnace and then chilled rapidly to glass by plunging the platinum crucible containing the melt into water. Cubes of about 1^{cm} edge were then cut from these glasses and subjected afterwards both to heat and stress. Heat was applied by means of an air-gas blast and concentrated by enclosing the preparation in a small reverberatory hood of asbestos. Pressure was produced in two different ways; in the first, a cube of mineral glass, shielded both above and below by thin disks of asbestos, was placed between two short vertical steel rods held in position by a suitable stand and gravity pressure obtained by weighting down the upper rod. By this method the effects of stress in one direction alone were studied, and the similarity of the textures produced compared with those of rocks formed under like conditions of stress.

To obtain stresses acting along two directions normal to each other and thus to imitate the pencilled texture of many amphibolites, a device suggested by Dr. A. L. Day was employed, consisting of a wide metal pipe ring of 12^{cm} diameter, into the sides of which four screws were inserted at intervals of 90°. Steel caps were fitted on the ends of these screws and between them the cube was placed. Pressure was applied by tightening the screws, while heat was derived as above from an air-gas blast.

After complete crystallization under stress, the cubes were immersed in hot Canada balsam and afterwards embedded in plaster of Paris. These precautions were found by experience to be necessary, and were taken in order that satisfactory thin slices could be cut from the cubes, which, after crystallization are extremely brittle and fracture readily. Plates were then

cut after the three faces of each cube and sections ground from them.

If the foregoing hypotheses are applicable in this case, the prismatic minerals crystallizing out of the glass under a stress acting in one direction only, should show in the center of the cube an arrangement along planes which are approximately perpendicular to the line of pressure; while the influence of a second stress at right angles to the first should cause the crystallites to grow along the one line of least resistance and show parallel orientation in consequence. Both of these textures were produced roughly in the cubes and were visible not only under the microscope, but also to the unaided eye.

Magnification 25×. Nicols crossed.

FIG. 1.—Section parallel to 100 through the center of a cube of wollastonite crystallized from the glass while under stresses acting in the direction indicated by the arrows.

For the sake of convenience in describing the phenomena observed, the cubes will be considered as fixed in position relative to the stresses applied, and the six cube faces as those of an isometric cube; the first stress being applied vertically and perpendicular to the basal planes (001) of the cube; the

second normal to the side planes (010), while the front and back planes (100) remain free in every experiment.

In view of the fact that more extended experimental work on the influence of stress on crystallization under bettered conditions is soon to be carried out in this laboratory, three photomicrographs of simple cases only are reproduced below. The results, here presented, are strictly qualitative and preliminary in character.

Figure 1 shows a plate through the central part of a large cube of wollastonite crystallized from its glass under stress

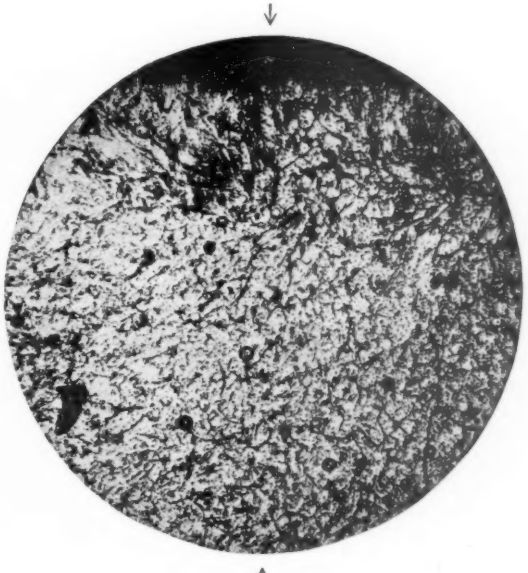
Magnification 25×. Nicols crossed.

FIG. 2.—Section parallel to 010 of a cube of anorthite crystallized from its glass under stresses in the direction marked by the arrows.

normal to 001. The section was cut parallel to 100 and in it the wollastonite fibers are oriented approximately perpendicular to the line of stress. Local variations occur and an individual fiber may occasionally be inclined at an angle of many degrees to the normal plane. Nevertheless, the general effect

of the aggregate is that of an arrangement of the fibers in layers parallel to 001; along this plane the cube also showed a tendency to split.

Figure 2 is part of a cross-section parallel to 010 of an anorthite cube crystallized from glass under stress normal to 001. The photograph shows the upper part of a section which was cut nearer the outer edge of the cube than that of the preceding figure. The effect of crystallization proceeding from the outer surface inwards because of the rapid heating and in spite of the counteracting forces, is clearly marked in this section. Only after the conditions of heating had become more uniform could the effect of the unequal stress find expression in the parallel arrangement of the fibers in the central portion of the cube as shown by fig. 1, and the lower part of fig. 2.



Magnification 25×. Nicols crossed.

FIG. 3.—Section parallel to 100 and near exposed surface of a cube of diopside crystallized from the glass under stresses indicated. The prismatic fibers were normal to 100 and are cut, therefore, crosswise by the section.

Figure 3 represents part of a thin slice taken from a crystallized cube of diopside glass parallel to 100 and very close to the exposed surface. The prismatic fibers which were the first to crystallize were normal to the exposed surface and are thus cut transversely by the section.

Résumé.

The schistose and gneissose textures of many metamorphic rocks have been ascribed by Van Hise and others to the orienting influence of pressures with a stress difference acting during the recrystallization of the rock in its new environment,—solution taking place along the line of greatest strain and deposition along the line of least resistance and normal to the maximum stress. In such cases the rock cleavage is due to the parallel arrangement of its mineral components in planes perpendicular to the line of greatest stress.

Conditions of experiment in which crystallization under unequal strains could take place were effected by using cubes of glasses made by chilling melts of different minerals rapidly, and by heating these to the point at which crystallization first began, the viscous glass at that temperature being still in a state of fair rigidity, and capable of supporting a certain amount of unequal strain.

Textures similar to those of certain metamorphic rocks were produced in this way, and an experimental confirmation of the theoretical deductions thus obtained.

Geophysical Laboratory, Carnegie Institution, Washington, D. C.

Art. XXI.—*Fractured Bowlders in Conglomerate;** by Marius R. Campbell.

During a visit to the Deer Creek coal field of Arizona, which the writer made in the autumn of 1903, countless numbers of fractured bowlders were found on the outcrop of a coarse conglomerate, which seemed to require unusual and peculiar surroundings to account for their present conditions. Accordingly some hasty notes were taken of field relations and a few typical specimens secured for further study. A group of these fractured bowlders is shown in figure 2 and the following descriptions may throw some light on their mode of origin.

The region in which the phenomenon was observed is an irregular syncline of Cretaceous and Carboniferous rocks in Pinal County, about ten miles east of Dudleyville at the junction of the San Pedro and Gila rivers, better known perhaps as the Deer Creek coal field.†

The rim of the syncline is in large part formed by the great Carboniferous limestone which also apparently underlies much of the central part of the basin, but it is effectually concealed by a great mass of later rocks consisting of lava, tuff, and beds of sandstone and shale. These beds are probably of late Cretaceous age, and, therefore, there is a great time-break between them and the underlying limestone, although in most cases the beds at the contact are apparently conformable.

The rocks immediately overlying the limestone generally consist of sandstone and shale with some small coal beds. Above this group there are many beds of andesitic tuff with interbedded sand and clay and what appears to have been great surface-flows of andesite. Some 500 or 600 feet above the base of the Cretaceous rocks is a bed of conglomerate composed of bowlders of all sizes up to 2 or 3 feet in diameter, held in a matrix of very soft andesitic tuff, a typical outcrop of which is shown in figure 1. This view was taken on Ash Creek just below the limestone box canyon east of Saddle Mountain and the bedding planes of the conglomerate dip 70 degrees to the left, or toward the center of the basin. The bowlders represent a great variety of rocks, both crystalline and sedimentary, but probably those of quartzite are most abundant.

This bed of conglomerate shows at a great many points, but in most places the matrix is so soft that the rock breaks down

* Published by permission of the Director of the U. S. Geological Survey.

† For a more detailed description of the region and the geologic relations see "The Deer Creek Coal Field, Arizona," by the writer. U. S. Geol. Surv., Bull. 225, pp. 240–258.

when exposed to the atmosphere, leaving only a mass of gravel and bowlders. The material is all well rounded, and it seems evident that it has been swept into its present position by strong currents of water, presumably by surface streams.

1

Bed of Cretaceous conglomerate on Ash Creek, Pinal County, Arizona. Andesitic tuff matrix. Dip 70 degrees to left. Bowlders fractured.

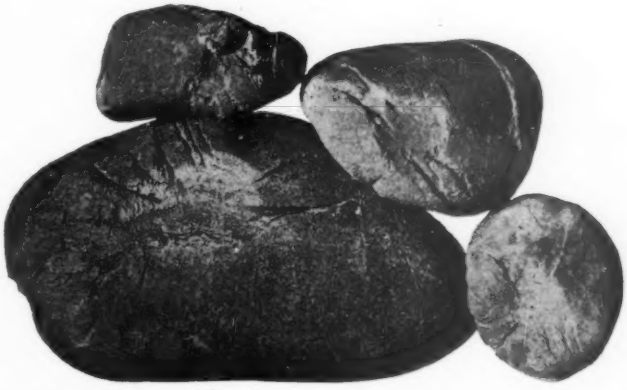
After the deposition of this material, the rocks were disturbed by what seems to have been the upthrusting of huge masses of igneous rocks, giving to the sedimentary beds the form of an irregular basin. In some places the movement has been quite severe, and the rocks are steeply upturned and

faulted, but in other places the movement has been gentle and the rocks dip lightly toward the center of the field.

At a point on the north side of the basin on the old Indian trail across Mescal Mountain to San Carlos, the bed of bowldery conglomerate dips toward the south or center of the basin at an angle of less than 10 degrees. The soft matrix of tuff has been dissolved and the bowlders are scattered over the ground in great profusion. At this place the specimens shown in figure 2 were found. They were not in position, but their original relations are apparent.

Almost every bowlder of the thousands scattered over the ground at this place is marked by one or more bruises where other bowlders have been pressed against it. Considerable movement is indicated by these bruises, for the surface is

2



Fractured bowlders from coarse Cretaceous conglomerate, Pinal County, Arizona. Scale, one-half natural size.

ground and crushed in a way that could only occur under repeated crushing strains. In some instances the opposing bowlder has failed to make an impression, probably because it was composed of softer rock, or because some more resistant bowlder took the strain, relieving the pressure in the surrounding material. The large bowlder shown in the cut has at least six bruises, the two most severe being the one on the front and the one at the left end seen in profile. At these two points the opposing bowlders have been forced into this one until it has been nearly broken to pieces. Great cracks have opened in various directions and the broken parts have been thrust out until it appears like a ball of partly hardened clay that has been squeezed from several directions. The other

bowlders show similar results, the two on the right being marked by especially deep bruises and great cracks which extend entirely through them. The bowlder on top has had another bowlder thrust into it so far that a piece of the opposing bowlder is still contained in the upper part. The bowlders in question are mostly tough quartzite and they present a striking illustration of the enormous pressure that has been brought to bear upon them.

Similar fractured bowlders may be seen in figure 1, but in this case they appear more like fractures due to shearing than the result of one bowlder impinging upon another. A good example may be seen above and to the right of the hammer where a bowlder 8 or 10 inches in length is sheared in three or four places. At first sight it might seem that only a few of the bowlders in this view are broken, but close inspection shows that almost all are more or less affected.

Such pressures as are shown by these bowlders are naturally associated in one's mind with intense folding, but this relationship is questionable. The bowlders shown in figure 1, where the bed is tilted at an angle of 70 degrees, are not so badly fractured as are those shown in figure 2 from the north side of the basin, where the dip is only 10 degrees. It must be stated, however, that where the bed occupies the center of the basin, as for instance at the place where the Dudleyville trail first reaches Deer Creek, a short distance east of the mouth of Little Rock Creek, the bowlders are not fractured, or at least fractures were not observed. The explanation of the phenomenon probably lies in the peculiar conditions under which the bowlders were held. If the matrix had been solid and homogeneous and closely attached to the bowlders, it is probable that no such fractures would have been produced, but under pressure the soft turf acted much like fluid material and all of the strain came upon the bowlders themselves. Not only that, but the bowlders were held so loosely that there was opportunity for the sides to give under pressure and consequently cracks were produced and even the entire side of the bowlder was shoved off to an appreciable extent. A glance at figure 2 makes it plain that the large bowlder could not have been crushed from the spot in front unless there was room for the side to expand on what is now the upper part. If this bowlder had been surrounded by a strong homogeneous cement no such fracture could have been produced.

The conclusion is, therefore, that such fracture can be produced only where the matrix is soft and flows under pressure, leaving the bowlders to take the brunt of the strain, and affording them no lateral support to prevent them being crushed under the strain.

Art. XXII.—*The Exploration of Samwel Cave;* by E. L. Furlong.

Introduction.
History of Discovery.
Description of Cave.
Character of the Deposits.
Method of Excavation.
Fossil Remains.
Age of Samwel Cave Fauna.
Possible Quaternary Artifacts.

Introduction.

The first active work in the exploration of caves in northern California was commenced in the summer of 1902. Though the presence of caves in the region was known for many years, yet no scientific work had been carried on in them. The excellent results derived from the exploration of Potter Creek Cave* stimulated exploration in this region for other caves. Of these the Samwel Cave† has furnished the most valuable results.

The cave investigations have been conducted under the auspices of the Department of Anthropology of the University of California. The exploration of Samwel Cave in 1905 was supported by a grant from the American Archæological Institute.‡

The work has been carried on under the immediate direction of Professor J. C. Merriam, whom the writer desires to thank for material aid in the work of exploration and in the description of the cave fauna. Thanks are due Mr. Walter King and Mr. William Boynton for valuable service rendered in excavating and removing fossil remains under somewhat hazardous conditions.

History of Discovery.

The initial exploration of Samwel Cave in Shasta Co., California, for scientific purposes was carried on in the summer of 1903. An interesting legend, the scene of which was laid in Samwel cave and told by a Wintun Indian, led to its exploration. This story has a double value in making known an important cave, and in the verification of the legend, which now becomes an interesting piece of Wintun history. The Wintuns believe that caverns are of supernatural origin and have used them as places of magic. A courageous Indian, who had any important undertaking in view, such as a long

* The Exploration of the Potter Creek Cave; by Wm. J. Sinclair, Publ. Univ. Calif., North Amer. Arch. and Eth., vol. ii, No. 1.

† Prelim. Note on Expl. of Samwel Cave, Science, N. S., vol. xx, p. 53; E. L. Furlong.

‡ The above is submitted as a part of a report on investigations carried on under a grant from the American Archæological Institute for cave explorations in California, under the direction of Professor F. W. Putnam.

hunting trip, or a war expedition, would hide himself in the cave for a certain period, fasting and meditating on the object desired. It was the belief that through this vigil they would obtain good luck and success.

Following is the version of the legend generally current among the Wintuns:—

Many years ago a woman of strong medicine told three Wintun maidens that this cave contained two pools of Sawame or magic water; and that if they bathed in these it would insure good luck and make their wishes come true. Acting on the old woman's advice, they entered the cave, lighting their way with pine torches. They found one pool of water in which they bathed, and then went in search of the second pool which contained the stronger Sawame. Following the instructions of the medicine woman, they climbed to the narrow entrance of a large chamber. Seeing no water here, they went hand in hand through this chamber and into the winding passages leading from it. In one of these they came to a large pit. One girl more curious and venturesome than the others went near the edge and looked down. Craning far over, her foot slipped and she fell over the edge. She would have fallen at once to the bottom but for the supporting hands of the other maidens. The overhanging wall at the edge of the pit was slippery and her efforts to regain the top were vain. The two girls above could with difficulty retain their footing and in their bewildered state did not have sufficient strength to lift her. At last, exhausted and slipping slowly toward the edge, they let go their hold and the unfortunate girl fell into the pit. They heard her strike, and then again far below a faint thud. They fled in fright from the cave and spread the news among their relatives and friends.

Some of the Indian braves went to the cave taking with them lengths of grass rope, which they knotted together and lowered into the pit. They seemed unable to touch the bottom with their rope and could do nothing. Hearing no sound below, after a time they left the place. They said the spirits had gotten the girl.

From this time on the cave was held in profound awe and was seldom if ever visited by the Indians. The white people who settled in the country soon after the event thought the tale was but an Indian myth and gave it little credence.

The first descent into the large chamber of the cave was made by Professor J. C. Merriam and the writer in August 1903, the other chambers having been investigated by our party a short time previous to this. The work commenced in 1903 has been continued during the past two summers.

Description of the Cave.

The Samwel cave is in the belt of Carboniferous limestone exposed along the lower portion of the McCloud river. It is situated about sixteen miles above the mouth and on the east bank of the river. The limestone ridge hollowed by the chambers is at the foot of a spur of Bollibokka Mountain.

FIG. 1. Location of Samwel Cave. The main entrance is covered by a group of trees on the face of the highest limestone cliff, and below the arrow. The Quaternary entrance to the lower chamber (chamber II) is in the brushy canyon to the right and below. The elevations of the three lowest terraces are given by the grassy flat to the right across the river, by the small patch of open ground to the right above the lowest terrace, and by the highest point on the limestone.

A small canyon which lies to the south has been cut partly through the limestone at its lower portion and leaves a perpendicular limestone cliff as its northern boundary. From this canyon a small cavern penetrates the base of the cliff about

70 feet below, and considerably to the east of the main entrance of Samwel Cave. As this cavern is closely associated with chamber two, it will be discussed with the deposits in that chamber.

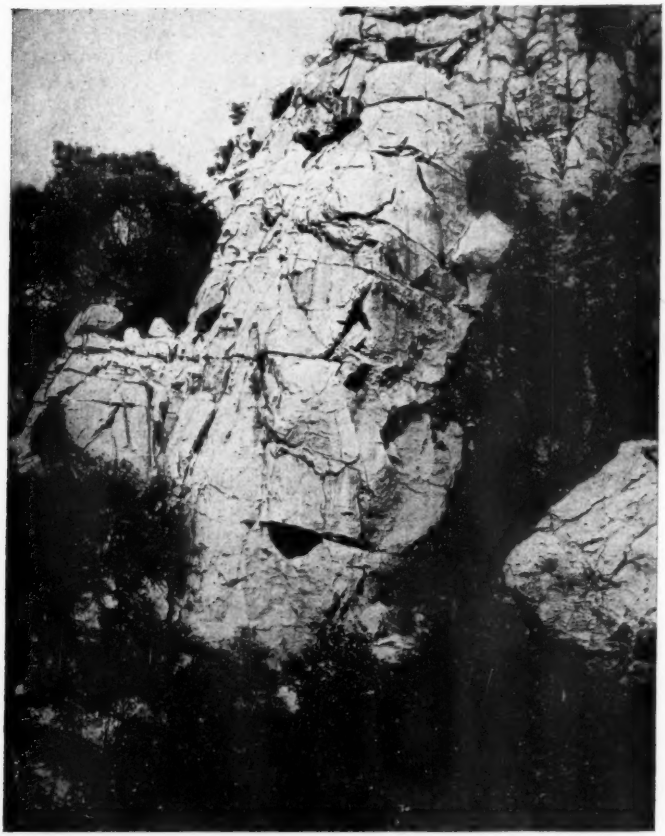


FIG. 2. View looking toward the cave from the canyon to the south. The existing entrance is behind the trees on a prominent rock shelf projecting to the left from the cliff. The Quaternary entrance to chamber two is behind and below the large fallen block to the right.

The main entrance is on a Quaternary river terrace. The terrace is 355 ft. above the McCloud and 1505 ft. above sea level. It is broad and relatively low and gives access to a large open chamber. The cave as a whole is about 352 ft. long and

exhibits considerable beauty in the curious forms of its chambers and in the numerous stalagmite and stalactite growths contained in them. The entrance chamber is 73 ft. long and 50 ft. wide with an average height of 6 ft. At the extreme northeast end a small opening leads to a long series of lower chambers. Of the latter, the two most important will be designated as chambers one and two.

The lowest portion of the floor of chamber one is 24 ft. below its entrance. From a bench 4 ft. from the floor of the northwest corner a narrow, almost vertical shaft drops a distance of 16 ft. to a winding series of chambers below. The first of these contains the first pool of water referred to in the Indian legend.

About on a level with the entrance to chamber one and its extreme northeastern part, a narrow opening leads to a series of rooms running to chamber two. These have a general trend from south to north. The north chamber contains the chimney-like opening to the chamber below. From the floor of chamber two many small grottoes lead out in several directions. At the southeasterly side a low-arched grotto leads to a passage way which will be discussed later.

Character of the Deposits.

The principal deposits are in chambers one and two. The deposit in *chamber one* partly fills a small fissure-like grotto which leads off from this room. It extends into the chamber and fans out, covering a portion of the floor. This deposit is 29 ft. long, an average of 4 ft. wide and is 8 ft. deep in its thickest portion. The section is as follows:

Reddish clay	·1 to ·3 ft.
Stalagmite capping	·1 to ? ft.
Earth mixed with angular gravel	·3 to 1·6 ft.
Breccia	2· to ?
A floor of stalagmite	·1 to ·3 ft.
Earth grading into breccia	1·2 to 4·4 ft.

The deposit was evidently formed by earth and limestone fragments falling from the outside, through an aperture at the top of the grotto. There is now no sign of such an opening. However, earth can be seen on the fissure walls and projections till the walls meet at the top.

That there was an intermission of sufficient time for stalagmite to form before the completion of the deposit is shown by the presence of the false floor. Probably the aperture was choked for a time and later reopened. All of the material of the deposit evidently came in at one place, as it is as much in the form of a low cone as the fissure will allow. The apex

was near the middle of the fissure with its sides sloping to either end.

FIG. 3. A portion of the floor of chamber two, Samwel Cave, after the greater part of the fossil material had been removed. The type skull of *Euceratherium* was still in the stalagmite to the left of the undisturbed skeleton of the Indian woman.

The deposit in *chamber two* has greater surface area but is much shallower than that in chamber one. Its greatest length is 36 ft. from north to south and greatest width 18 ft. From north to south it is on an incline plane, the southern end being

5 ft. below the surface level at the north end. It is composed of thin beds, as follows:

Fine-grained reddish clay	·01 to ·4 ft.
Stalagmite capping	·1 " ·4 "
Mixed earth and gravel	1· " 2· "
Stalagmite	·05 "
Fine earth and gravel	·2 "

This shallow deposit was derived from material in the cave chamber, angular limestone gravel, stalagmite formed from dripping, and from very small streams of water carrying in material. The earth and clay were carried in by the water and possibly some part of it was tracked in by animals.

On the southeast side a grotto leading off from the chamber shows the sloping stalagmite-covered surface of a deposit that fills a large space between the outside, canyon entrance before referred to and chamber two. The deposit was tunneled through, thus making open communication between the surface and this chamber. The deposit is 56 ft. long, running approximately southeast by northwest; its greatest depth is 28 ft. Its surface in the canyon entrance is covered by blocks of limestone. The deposit in this portion of the cave has been intermittent in its deposition. Strata of mixed earth and gravel and of red earth occur. In about the middle of the beds, in vertical section, a thick flooring of stalagmite appears. It is thicker at places where there has been drip from the roof.

The material of this deposit was carried in by wash and slide from the entrance during the cutting of the canyon. It filled a former entrance of chamber two.

Method of Excavation.

As in the Potter Creek cave, the deposits were sectioned off in numbered squares of 4 ft. That of chamber one was first excavated. A cut was made in the deposit at the entrance to the fissure and carried through to the inner end. The fossil material was removed from benches a foot deep and each specimen labeled as to horizontal and vertical position. As the digging progressed, the waste material was thrown back to the hard floor in chamber one. It was necessary in working through the breccia to use powder and blast, though this was detrimental to the fossils contained in the breccia.

Previous to the opening of the outside passage way to the grotto in chamber two, a ladder 85 ft. long was necessary to gain access to its floor. For this purpose a rope ladder with wooden rounds was used. Two holes were drilled in the floor of the chamber above. In the holes drills were securely imbedded. Thimbles that were fastened in the free upper ends of the ladder were then dropped over the drills and tied

there. The ladder hung free from its upper fastenings to the floor below.

The deposit in chamber two was also sectioned off and the dirt removed section by section. Specimens were frequently cemented by stalagmite to the hard floor at the bottom of the deposit and had to be freed by the use of gads.

The discovery of specimens imbedded in the surface of a stalagmite-covered slope led to the excavation in the southeast grotto leading from chamber two. A low tunnel 20 ft. long was run through this deposit in a southeasterly direction. At the farther end a space 8 ft. high by 4 ft. wide was hollowed out. Falling blocks of stone and the danger of a sudden caving in of the loose dirt above made a discontinuance of the work at this place necessary.

With the object of ascertaining the distance of the tunnel workings from the canyon outside, Professor Merriam made a series of measurements with compass and a tape line from the far end of the tunnel to the top of chamber two and through the winding passages of the cave to the canyon grotto outside. These measurements indicated that the small cave at the base of the cliff in the canyon was but a few feet from the inner tunnel workings. Work was then commenced in the floor of the canyon cave. A shaft was sunk 4 ft. square by 10·5 ft. deep, at which depth a stalagmite floor was encountered. At this place a strong draught of air which made the candles flicker was noticed coming from a stratum of gravel in the cave. A drift 8 ft. long was run at right angles to the shaft in a northeasterly direction. As the drift progressed the draught had perceptibly increased and become so strong and cold as to make working uncomfortable. On continuing in the same direction an opening was made to a series of two sealed grottoes. The surface of the deposit slope formed the floor of these. Signals had been previously arranged so that a person knocking against the walls in the tunnel from chamber two would be understood if heard by those above. When excavation had reached the sealed grottoes, signals could be distinctly heard close by. In moving about the floor to locate the signals from chamber two, we suddenly heard a voice below warning us to move carefully or we should break through. It was found that a distance of only about one and one half feet intervened between the tunnel and the grotto above, and a moment's work with a shovel opened communication with the chamber below.

Fossil Remains.

The deposits in *chamber one* contained a relatively large quantity of material. Teeth and bones of extinct species were found on the surface. Many complete bones were taken

from the loose earth and gravel, also numerous teeth. Fragments and split bones were plentiful. The breccia layer was exceptionally rich in remains. Most of the specimens are in a fine state of preservation. Those on the surface had a coating of stalagmite of varying thickness. When the stalagmite was removed the bone was found to be white and fresh looking although it contained no organic matter. The specimens from the earth were more or less discolored though in good condition. The bones of young individuals in some cases were in a crumbling condition. In the gravel layers a thin incrustation of stalagmite covered the bones. Some old rodent burrows were dug into the upper layer of earth and in these recent rodent remains were numerous. The fragmentary material consisted principally of split pieces of narrow bones. The pieces were in most instances gnawed around their edges by rodents, the marks of the incisor teeth being distinct. Some fragments show long grooves and roughened places on the surface as if they had been crushed between the teeth of large carnivores.

The fossils in this deposit had access through the same opening as the earth and gravel and were deposited with it. That probably there were two distinct periods of deposition is shown by a slight difference in fauna in its top and bottom layers. In the lowest portion of the deposit ground-sloth (*Megalonyx?*) teeth occur, but they are absent in the top layers. So far there are 20 species recognized; of these 8, or 40 per cent, are extinct.

Following is a list of species from the fissure deposit:—

Ursus americanus Pallas.
Ursus, n. sp.
Vulpes, sp.
Putorius arizonensis Mearns.
Aplodontia major Merriam C. H.
Aplodontia near *major* Merriam C. H.
Aplodontia rufa Rafinesque.
Arctomys, sp.
Lepus auduboni Baird.
Thomomys, sp.
Thomomys monticola Allen.
Citellus douglasi Richardson.
Sciurus, sp.
Erethizon epixanthus Brandt.
Euceratherium collinum Sinclair and Furlong.
Haplocerus, sp.
Odocoileus, sp.
Equus occidentalis Leidy.
Elephas, sp. (tooth fragment)
Megalonyx, sp.

The area of deposit in *chamber two* when first viewed presented an interesting spectacle. Its surface was strewn with skulls and limb bones. Near the foot of the ladder lay a cougar skull. It was covered with stalagmite an inch thick but showed the outlines of skull perfectly. Imbedded in stalagmite, the limb bones of the same individual were lying near it. Near the middle section the skeleton of the unfortunate Indian woman was stretched on its side. The pelvic girdle and skull had a thin film of stalagmite crystals over them, and the remainder of the bones were covered by a soft black mould. Near the human skeleton lay the type specimen of *Euceratherium**. In the surface clay and lying loosely about were several raccoon skeletons. Porcupine and other rodent bones were plentiful. Mammal remains were abundant from the top of the deposit to the hard floor below. In the clay and on the stalagmite capping the fossil remains of several Myriopods were found, the exoskeletal structure and form being perfectly represented.

On some of the higher slopes in chamber two and in most of the grottoes there were a number of small skeletons. Of these, several were porcupines and raccoons. An almost complete porcupine skeleton with the bones lightly covered by stalagmite was found in one of the grottoes. In most instances the enveloping stalagmite tended to keep them in perfect condition. A marked feature of the specimens deposited at this place was the completeness of several skeletons and the unbroken condition of skulls and limb bones. For this reason the supposition of entrance through the opening 85 feet above would be improbable. The presence of entire skeletons of bear, cougar, *Preptoceras* and small carnivores led to the belief that the animals with the exception of the ungulates had free access to the cave at some previous time. The later work of excavating from the southeast grotto to the canyon cave proved the belief to be correct. From the slope in the grotto, where the tunnel was run, to within 8 feet of the surface at the outside entrance, scattered parts of individuals like the animals in the main deposit were found. The well-known hibernating habit of bears readily accounts for their presence in the chamber. At the present time hunters in that region make the rounds of the known caves where bears are in the habit of housing for the winter. It is not uncommon for cougars to use such places for a lair. It is not improbable that bears and cougars used chamber two when entrance was possible. It is true such animals do not care to go far from the light, but it would not have been necessary during the time the cave was inhabited. The deposit filling the old

* Furlong and Sinclair, Bull. Dept. Geol. Univ. Calif., vol. iii, p. 411.

entrance is of considerable extent and fills a large space that when clear would probably permit rays of light to penetrate to some of the deeper parts of the chamber.

That bears and cougars prey on ungulates and smaller mammals is well demonstrated in the present day, and the finding of large quantities of scattered and broken ungulate material, such as deer, *Euceratherium*, *Preptoceras* with many rodents, as rabbits and gophers, supports the view that they were brought in by carnivores. The large carnivore skeletons were found in several cases to be nearly complete and but little disturbed, and the supposition that the carnivores inhabited the cave and were in the habit of dragging their prey to the lair to feast on it at leisure, is probably correct.

Following is a list of the species represented in chamber two and in the deposit leading from the chamber. There are 21 species, of which 6, or 28·5 per cent, are extinct.

Ursus, n. sp.
Ursus, sp.
Urocyon townsendi Merriam C. H.
Procyon near *lotor* Linn.
Felis near *hippolestes* Merriam C. H.
Mephitis occidentalis Baird.
Mustela, sp.
Aplodontia near *major*.
Erethizon epixanthus Brandt.
Lepus auduboni Baird.
Lepus, sp.
Microtus, sp.
Neotoma fuscipes Baird.
Neotoma, sp.
Sciurus, sp.
Citellus douglasi Richardson.
Euceratherium collinum Sinclair and Furlong.
Preptoceras sinclairi Furlong.
Odocoileus, sp. (*a*)
Odocoileus, sp. (*b*)
Megalonyx, sp.

Age of Samwel Cave Fauna.

The Samwel fauna through its percentage (over 30 per cent) of extinct species, and its typical Quaternary species, as the ground-sloth, *Equus occidentalis*, *Teonoma spelæa? Ursus* n. sp., *Elephas*, *Euceratherium* and *Preptoceras*, establishes its age as Quaternary.

A comparison of the species from chamber one and chamber two shows a greater percentage of extinct species from the former. That the remains may have had entrance to chamber one many years before it was possible for chamber two to be

used by animals or for their remains to reach it, is shown by the relative positions of the two entrances. Though the former entrance to the fissure in chamber one is closely sealed, its outer opening could only be from the top of the cliff the cave is in. The entrance to chamber two from the canyon bed is a hundred or more feet below the point where the fissure entrance was probably located. The additional time required for cutting of the canyon to the depth of the lower entrance would be considerable.

The foregoing reasons, viz: the faunal difference and the probably greater age of the entrance to chamber one, tend to show that the fissure deposit is older than the deposit in chamber two.

While the faunas of Potter Creek Cave and Samwel Cave are both Quaternary and are closely allied, there are some differences that suggest difference in age. *Preptoceras* and the Porcupines are present in Samwel Cave and absent from Potter Creek Cave. *Arctotherium*, *Camelus*, and *Mastodon* are present in Potter Creek Cave and absent from Samwel Cave. These faunal differences are probably to be correlated with a difference in the physiographic relations of the Samwel Cave and indicate that it is of somewhat later origin than the Potter Creek cave. In support of this hypothesis, the river terraces of the McCloud canyon offer some evidence.

On both sides of the McCloud canyon at Samwel Cave several distinct terraces are visible. Across the McCloud, south of Bollibokka, well-defined terraces are cut in Hirtz Mt.; the lowest of these is 27 feet above the river. Above the latter, approximately 150 feet higher, is a smaller terrace. Between this and a terrace approximately 300 feet higher several small benches occur. The 177 ft. terrace corresponds to a level but a short distance below the canyon cave entrance. The 300 ft. terrace is on a level with the top of the cliff over the main entrance to the cave. One of the small benches between the 177 and 477 ft. terraces corresponds to the level of the main entrance itself. It is probable that when the McCloud river flowed at a level 477 ft. higher than its present height opposite the cave, and when making the terraces at that height on Hirtz Mountain, the cave was being partly carved out by solution and subterranean water flow. During subsequent river cutting to the terrace in front of the upper cave entrance, the large chambers were formed. The time represented by the cutting between this last terrace and the one just below the canyon entrance was the period when mammals inhabited portions of the cave and the deposit in chamber one was formed. During the latter part of this period chamber two was opened and occupied. When the river cut to a still lower level and the

canyon on which the lower cave entrance opens was deepened, the lower entrance was gradually filled.

The terrace 477 ft. above the river on Hirtz mountain corresponds to the level of the top of the cliff over the Samwel Cave and probably represents also the present elevation of an early terrace stage mentioned by Dr. Sinclair.* It is 240 ft. above the river level at Baird and is represented by gravel-strewn terraces at that height. This being the case, considerable time must have elapsed after the opening of Potter Creek Cave, which opened at the 800 ft. level and prior to the opening of the Samwel Cave.

Possible Quaternary Artifacts.

In the course of excavation numerous split bones were encountered. Most of these have many marks made by rodents and large carnivore teeth. Some have been gnawed around their entire edge. Split bones were also found that have polished surfaces like some of those described by Sinclair from the Potter Creek Cave.

A piece of chipped lava was removed with some bones a few inches below the surface in the deposit in chamber one. It was found after the firing of a blast and may have fallen in from the surface, though its being covered by a film of stalagmite may support the belief that it was in place.

A chipped obsidian was removed from a bucket of earth and gravel hoisted from a depth of several feet while sinking the shaft through the deposit filling the lower entrance to chamber two.

The description and discussion of the archæological value of these specimens by Professor F. W. Putnam is in press at the time of writing this report.

University of California, May, 1906.

* Univ. Calif. Publ. Am. Arch. and Eth., vol. ii, No. 1, p. 24.

ART. XXIII.—*Occurrence of Unakite in a New Locality in Virginia;* by THOMAS L. WATSON.

THE name unakite was proposed for a unique variety of granite composed of the essential minerals epidote, pink feldspar and quartz, from the Great Smoky Mountains, a portion of the Unaka range of the Blue Ridge, which marks the boundary between Tennessee and North Carolina. The type locality, Madison county, North Carolina, and Cocke county, Tennessee, was first described by Bradley in 1874,* and the specimens were from the slopes of the peaks known as "The Bluff," "Walnut Mountain," and "Max's Patch," Cocke county, Tennessee, and Madison county, North Carolina.

Later, a second locality in which this rare variety of granite occurs was noted in the Blue Ridge at Milam's Gap, near Luray in Page and Madison counties, Virginia. Phalen† visited and studied the unakite in the Virginia area and, in 1904, published a preliminary paper on the occurrence and petrography of the unakite and its associated rock.

The occurrence of the unakite in the two widely separated areas is somewhat similar, but the unakite-bearing rock is different in each locality. In the North Carolina–Tennessee area the unakite-bearing rock is an epidote-bearing mica granite which, in places, contains little or no quartz and becomes syenitic.‡ The unakite-bearing rock in the Milam's Gap area of Virginia is reported by Phalen to be a hypersthene akerite. In both localities the epidote of the unakite has been proved by Watson and Phalen to be secondary.§

In a recent trip to Ashe county, North Carolina, the writer collected specimens of typical unakite from Grayson county, Virginia, a locality not hitherto reported, so far as the writer is aware. Specimens were collected along the Marion-Jefferson public road, about two and a half miles south of Troutdale, a railroad terminus near the crest of Iron Mountain, in Grayson county, Virginia. Time was insufficient to prove the extent of the area or to study the occurrence and association of the rock. Loose angular masses of moderate size of the unakite were observed for some distance along the roadside and the specimens taken closely resemble those from Madison county, North Carolina. The rock (unakite) is composed of dominant yellow-green epidote, deep pink feldspar and quartz, with no trace of a ferromagnesian silicate indicated.

* This Journal, vol. cvii, pp. 519–520, 1874.
† Smithsonian Miscellaneous Collections, vol. xlv, pp. 306–316, 1904.
‡ Watson, Thomas L., Journal of Geology, vol. xii, p. 395 et seq., 1904.
§ Loc. cit.

Geological Department, Virginia Polytechnic Institute,
Blacksburg, Virginia, June, 1906.

Art. XXIV.—*Types of Permian Insects;* by E. H. Sellards.

In the October, 1903, issue of this Journal the writer noted briefly the discovery of insects in the Permian of Kansas. The material is of exceptional interest as giving the most complete record of Permian insect life thus far obtained. Somewhat over two thousand specimens are now at hand and indicate the richness as well as the interesting character of the Permian insect fauna. For the present paper, leading types from the collection are selected for description, a full account of the fauna as a whole being reserved for subsequent monographic treatment. Unless otherwise indicated, the type specimens described are in the writer's collection.

Part I.—*Odonata.*

Odonata have not been obtained previously from the Permian. Several genera are known from the Coal Measures, those from the Commentry Coal Measures of France being particularly well known through the researches of Brongniart.* In the Mesozoic the group is fully represented by a rich series of specimens from the Solenhofen deposits. The American Permian specimens give, therefore, a welcome addition toward a fuller history of this interesting line of insect development.

The foundation studies of Comstock and Needham,† together with the special study of dragon-fly wing venation by Needham,‡ have afforded for the classification of the dragon-flies a basis much more secure than has been available heretofore. In seeking types among the living genera with which to compare the fossil forms, I have found it convenient to go repeatedly to Needham's paper, as being, in the absence of a large dragon-fly collection, the most accessible and most reliable source of detailed information regarding the wing venation of the modern forms. I very gladly express my indebtedness to these authors for their valuable investigations, without which a study of the Permian types would have been attended with much greater difficulties.

The following discussion is based, so far as it concerns Permian forms, on the exceptionally well-preserved specimen illustrated by the accompanying figures, 1 to 6. The genus and species are new and I suggest that this type be known as *Tupus permianus.*

* Récherches pour servir a l'Histoire des Insectes fossiles des Temps primaires, Charles Brongniart, pp. 394–406, 1893.

† The Wings of Insects, by J. H. Comstock and J. G. Needham, Amer. Nat., vol. xxxii, 1898, and vol. xxxiii, 1899.

‡ A Genealogical Study of Dragon-fly Wing Venation, Proc. U. S. Nat. Mus., vol. xxvi, pp. 703–764, pls. xxxi–liv.

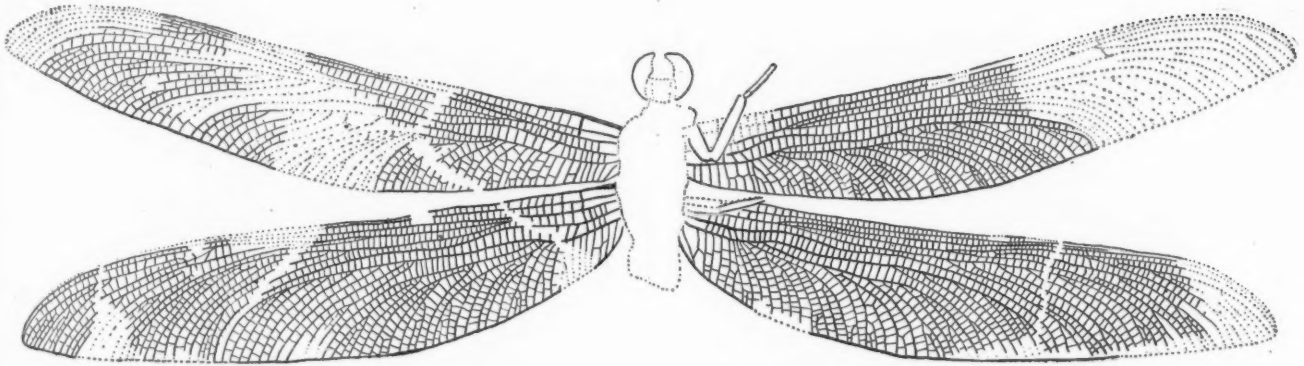


FIGURE 1.—*Tupus permianus* gn. sp. n. Type specimen slightly reduced. The specimen as illustrated is viewed from the ventral side, the base of the wings passing under the body. The strongly outlined structures on the under side of the head are apparently the mandibles, which in this as in European Paleozoic forms are unusually strong. The distal end of the femur, the tibia and a part of the tarsus of the left front leg is preserved, as is also a small part of the tibia of the second pair of legs. The tibia is spinous and the legs appear not to have been strong.

In the description to follow, the wing is considered by areas, as in this way its relations to earlier and to later forms are more readily indicated.

The base of the wing.—The base of the modern dragon-fly wing represents, as is well known, some very characteristic features. The costa is strong and marginal or with merely a narrow expanse of thickened membrane. The subcosta lies at the bottom of a deep fold. The radius and media are fused at the base and lie at the top of a corrugation. The cubitus appears in the basal part of the wing as a strong vein at the bottom of a furrow. The anal, also a strong vein, lies in turn at the top of a fold. Essentially the same features are presented by the base of the wing of Coal Measures and Permian dragon-flies, thus affording a starting point in homologizing the wing veins of Paleozoic and modern types. A clear recognition of the homologous parts at the base of the wing is of great importance in following the further interpretation of the veins throughout the wing, and I introduce here for comparison the base of the wing of a modern dragon-fly with that of the Permian form (figs. 2 and 3).

The costa.—The costa, as indicated, is in essential agreement with that of modern dragon flies. The genera thus far made known from the Commentry Coal Measures have, according to the illustrations of Brongniart, a more distinct precostal area than has *Tupus*. The one genus known from the American Coal Measures, *Paralogus* Scudder, in which this basal area is preserved, has, according to Scudder,* the subcosta (mediastinal) close to the margin.

The subcosta.—The subcosta continues simple, reaching usually beyond the middle line of the wing, gradually approaching and merging in the margin. In the modern forms the subcosta terminates at the strong cross vein forming the nodus. This special modification is concerned chiefly with the specialization of cross veins and will be considered under that head.

The radius and media.—The radius and media separate at a distance of from $1\frac{1}{2}$ to 2^{cm} from the base, the media going off at an oblique angle. Radius$_1$ continues as a simple vein to the apex of the wing. The media divides immediately after separating from the radius. The two resulting divisions admit of interpretation as the homologues of the veins marked in all of Needham's figures as M_{1-3}, and M_4, the upper division (M_{1-3}) falling into a furrow, the lower (M_4) topping a fold. Their subsequent divisions likewise admit of homologizing in the same way. M_4 runs in

* Insect Fauna of the Rhode Island Coal Field, Bull. U. S. Geol. Survey, No. 101, p. 20, pl. 1, figs. *a* and *b*, 1893.

a curved course and reaches the inner border well toward the apex, and has, as is usual with the general run of Odonata,

2

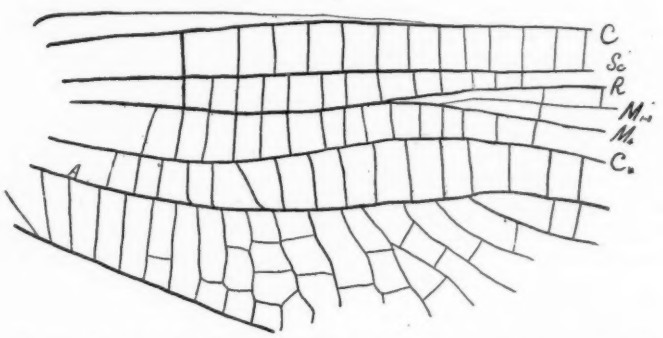


FIGURE 2.—Base of the right front wing of *Tupus permianus*. C, costa; Sc, subcosta; R, radius; M_{1-3}, branches 1 to 3 of media; M_4, fourth branch of media; Cu, cubitus; A, anal. Drawn with the camera lucida; enlarged four diameters.

particularly Odonata Anisoptera, a considerable number of veins from the lower side filling the space between itself and the cubitus. M_3 separates from M_{1-2}, and, again agreeing to a surprising degree with M_3 of Anisoptera, runs in a curved course parallel and close to M_4. No interpolated veins appear between M_3 and M_4. M_{1-2} divides opposite the subnodus; from this point both divisions continue as simple veins, presenting again an unexpected agreement with Odonata Anisoptera.

3

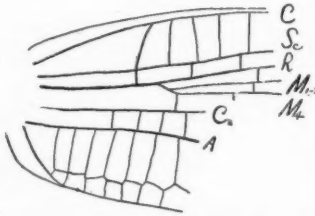


FIGURE 3.—Base of the wing of a modern dragon-fly. Lettering and enlargement as in figure 2. Both wings are viewed from the ventral surface, the body obscuring the extreme base of the wing.

Radial sector, subnodus, and oblique vein.—It is a well-known fact that to recognize the radial sector in the adult dragon-fly wing is often a matter of difficulty. With the Paleozoic forms, the adults only of which are available, we must therefore expect to recognize the radial sector, as a rule, from its relation to other veins rather than from any evidence in the sector itself. Fortunately, however, in most dragon-flies structural evidence bearing on the position of the radius is not wanting even in the adults. The keen observations of Need-

ham emphasized the fact that there exists in the wing of most adult dragon-flies a persistently oblique cross vein lying usually at or just beyond the separation of M_{1-2}; also a similar oblique vein above, uniting the radius and M_1. From the nymph wing it was found that the trachea of the radial sector crosses $M_{1,2}$, and that the oblique apparently cross veins are in fact parts of the sector. An examination of this region on the Permian genus *Tupus* reveals the presence of such an oblique vein arising from M_2 at a point just beyond the separation of M_1 and M_2; also an equally well-marked oblique vein, the subnodus, connecting the radius and media. Bearing in mind the complete agreement of all other veins of the radio-medial area with those of the same area in modern Odonata, there can

4

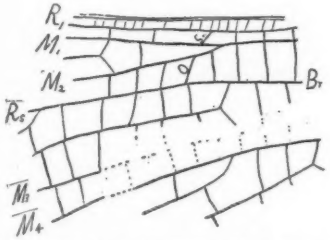


FIGURE 4.—Enlarged detail of the region of the subnodus of *Tupus permianus*, taken from the right front wing. Sn, subnodus; O, oblique vein; Br, bridge; R, radius; M_1, first main branch of media; M_2, second main branch of media; Rs, radial sector; M_3, third, and M_4, fourth main branches of media. Enlarged 4 diam.: drawn with camera lucida.

5

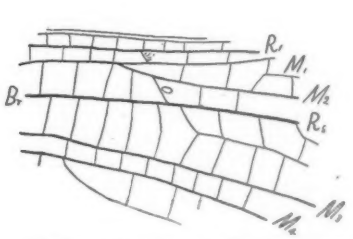


FIGURE 5.—Same area from the left hind wing of *Tupus permianus*. Enlargement and lettering as in figure 4. In this wing there is a slight depression (not shown in the figure) running from the subnodus toward the oblique vein.

scarcely remain a doubt as to the meaning of these two oblique cross veins. They clearly indicate a crossing of the radial sector. The area of the wing in the region of the crossing of the sector is shown enlarged in the accompanying camera lucida sketches. The fundamental significance of the crossing of the sector as a bond or relationship between Paleozoic and modern forms is too obvious to require further emphasis.*

It will be observed that in this Permian genus there is apparently a loss of that part of the sector lying between M_1 and M_2.

*Handlirsch's statement, Revision American Paleozoic Insects, p. 689, with reference to the Protodonata, that the "intersection of the longitudinal veins" is "still entirely wanting," can not, I feel sure, be maintained in view of the evidence here presented. The agreement of the veins of the entire radio-median area is altogether too complete to admit of explanation on any grounds other than that of strict homology.

In the left hind wing there is a slight depression not shown in the illustration, continuing the subnodal vein and running toward the oblique vein, indicating possibly the position of the vein or trachea. A comparison of the position of the subnodus

6

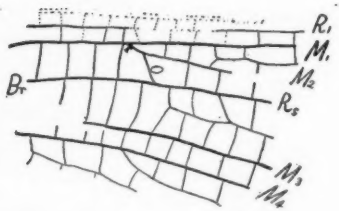


FIGURE 6.—Same area from the right hind wing of *Tupus permianus*. Dotted lines indicate restored border of the wing lost from the breaking of the matrix. Enlargement and lettering as in figures 4 and 5,

7

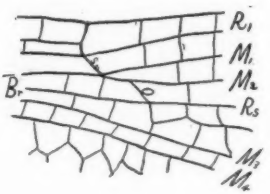


FIGURE 7.—Same area from the wing of a modern dragon fly. Enlargement and lettering as in former figures.

and oblique vein as seen in *Tupus* with the position of the trachea as seen in many modern nymphs is instructive. From the nymphs it will be seen that the trachea often lies across the media beyond the separation of M_1 and M_2, occupying approximately the position of the subnodus and oblique vein of *Tupus*. In the adult condition of modern dragon-flies the subnodus, as a rule, meets the media just at the point of separation of M_1 and M_2. It is probable that the subnodus has migrated in modern adult dragon-flies to its present position from an earlier primitive position, sometimes beyond the forking of M_{1-2}, sometimes perhaps basad of that point. As a result of its important function as a brace the subnodus is held firmly in place, while the oblique vein, serving no such responsible function, is much less constant in position.

8

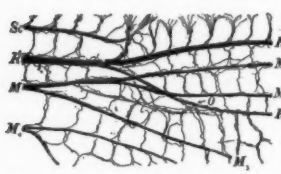


FIGURE 8.—Position of trachea of same area of modern nymph dragon-fly, genus *Didymops;* after Needham. Lettering as above. The indistinct trachea preceding the bridge is present, although not lettered.

The cubitus.—Cu_1 continues from the strong basal origin as a simple sinuous vein meeting the inner border slightly beyond the middle line of the wing. It is observed that the various genera of modern dragon-flies differ not a little among them-

selves in the disposition of the cubitus. With the advanced Anisoptera there is, as demonstrated by Needham, an abrupt bend in the cubitus just back of the arculus, the bend thus made forming the base of the triangle. With the Zygoptera the bend is much less conspicuous and the sinuous or uniformly curved type of Cu_1 is the rule. The Zygoptera have thus retained a cubitus much less differentiated from that of the Permian form than have the Anisoptera. The course of Cu_2 in the Odonata is one of the highly characteristic peculiarities of that unique order. Its distinctive feature lies in the fact that immediately after leaving Cu_1 it fuses with the first anal, continuing that vein and giving in the adult the appearance of a single strong vein from the base of the inner border. In those advanced Anisoptera in which the cubitus is most abruptly bent, Cu_2 is given off at the point of closest approach to the anal. With those more generalized Odonata in which the cubitus has a sinuous course, the basal part of Cu_2 appears as a cross vein. It is hardly to be expected that the particular cross vein representing the basal part of Cu_2 can in all cases be recognized in the fossil genera. It is to be noted, however, that in the Permian genus *Tupus* a cross vein some distance from the base becomes conspicuous by its strongly slanting position (fig. 2). A similar slanting cross vein is seen in Scudder's careful illustration of the Coal Measures genus *Paralogus*.*

The characters thus far discussed are those which concern the distribution of the main veins of the wing, and as such are without doubt the structurally more important characters of the wing. In these characters there is found to exist essential agreement throughout between Paleozoic, Mesozoic, and modern dragon-flies. That there are differences, many and obvious, scarcely needs stating. Such differences as exist, however, are associated almost wholly with the specialization of cross veins and as such are of secondary importance. They are conveniently discussed under the heading of cross veins.

Cross veins.—Specialization of cross veins plays a leading part in the development of mechanical strengthening devices with which the wings of modern dragon-flies are so richly supplied. With the Paleozoic dragon-flies, however, the cross veins are but little differentiated among themselves. Such specialization as has occurred has taken the direction principally of the matching of cross veins and is most advanced in the basal and dorsal part of the wing. In the Permian genus *Tupus* there is observed near the base a strong brace corresponding to the triangular brace at the base of the wing of

* Bull. U. G. S., No. 101, pl. i, fig. a.

many modern genera. Lines of matched cross veins are seen also in the basal part of the wing (fig. 2).

Nodus and stigma.—On the Paleozoic genera thus far known, both nodus and stigma are apparently lacking. Since the nodus is recognized as merely a strongly developed cross vein running from the costa to the radius, at which cross vein the subcosta usually terminates, the existence of a weak nodus on some of the more specialized late Paleozoic genera need occasion no surprise. It is to be expected that the subcosta will in early types reach beyond the cross vein, the nodus appearing simply as a strong cross vein from costa to subcosta, matched with a similar strong cross vein from subcosta to radius. Much the same may be said of the stigma, a strengthening structure thus far not observed to occur on these early Odonates.

The arculus.—A very conspicuous structural feature of the modern dragon-fly wing is the arculus. As is well known, the arculus of this, as of other orders in which it occurs, consists in part of the media directed obliquely at its point of origin from the radius, and in part of a strong cross vein from the media to the cubitus. The arculus, as a conspicuous feature, is absent from the wings of Paleozoic dragon-flies; yet the elements which compose it are there and in their respective positions. For the formation of a characteristic arculus there is needed scarcely more than a slightly accentuated bend of the media at its separation from the radius and a correlated strengthening of the cross veins bearing the chief stress in the support of the media. Along with this will go naturally the more or less complete disappearance of the now unnecessary accessory cross veins.

Triangle and quadrangle.—The structures known as triangle in the Anisoptera and as quadrangle in Zygoptera result, as in the case of the arculus, from specialized cross veins in conjunction often with a modified course of the adjoining main veins. The base of the triangle of the Anisoptera is formed by the cubitus, and results from an abrupt bend of that vein just beyond the arculus. The sides of the triangle are formed each by a cross vein running from the cubitus to the media. With the Zygoptera, in which the bend of the cubitus is less abrupt, there is naturally a less well-marked structure in this region, and as the arrangement of cross veins gives to this area a quadrangular rather than a triangular shape, Needham has proposed to designate it as the *quadrangle.* As has been noted above, the cubitus of the known Paleozoic forms agrees with that of the generalized modern Odonates in its sinuous, rather than abruptly bent course. With the most generalized of modern Odonates the quadrangle or triangle, as conspicuous

features, can scarcely be said to exist. To this extent they approach the Permian type.*

The bridge.—To the supplementary longitudinal vein interpolated between M_{1-2} and M_3 and connecting with the radial sector, Needham has applied the term *bridge*. The bridge appears as a normal feature in *Tupus*. A part of the bridge is seen also in *Paralogus*. Unfortunately the tip of the wing of that genus is not preserved. The crossing of the radial sector has doubtless promoted the early development of this structure.

Classification.

In the scheme of classification of Paleozoic insects proposed by Professor Samuel H. Scudder, the Paleozoic dragon-flies were disassociated from their modern descendants and placed along with all other Paleozoic insects in the Paleodictyoptera. Brongniart (Récherches des Insectes fossiles) places the Protodonata as a family group under the large order of Neuroptera. Professor Anton Handlirsch, in his recent publication (Revision of American Paleozoic Insects) has advanced the Protodonata to ordinal rank to stand as a Paleozoic order coördinate with the Odonata of Mesozoic and modern times.

It will be remembered that Professor Scudder, in defense of his general plan of classification, has urged repeatedly that the insects of the Paleozoic were more closely related *inter se* than to their descendants of the Mesozoic and later times. A classification based upon Scudder's principle must, in the nature of the case, break down with the advance of knowledge of extinct forms, for as the life history of the various lines of descent is continuous, it necessarily follows that the artificially placed dividing line between the Mesozoic and Paleozoic can remain a distinct break only so long as there remains time for a considerable development between the earliest known Mesozoic and the latest known Paleozoic representative of that particular line. In Scudder's classification emphasis is thrown on the interrelation of associated but diverging groups, or what may be called the lateral relation of organisms, rather than on the lineal or phylogenetic relations. In this connection I have urged a principle of classification† by no means new in its application, as follows:—"Any natural group of organisms should be recognized as extending back in time until a point is reached at which that group coalesces with a group or groups of coördinate rank, or unites with the parent stock." The principle proposed by Scudder necessitates breaking phyla,

* As a genus with cubitus unexpectedly similar to that of *Tupus*, compare *Pseudophœa*.

† This Journal, vol. xviii, p. 121, 1904.

the earlier members to be grouped with the parent or associated phyla, while the later stand in our classification under distinctive names. The line selected as the point at which to break the various insect phyla was the imaginary line dividing Paleozoic and Mesozoic—a line subject to change with the advance of stratigraphy and paleontology and in any case confessedly a line of convenience. A more natural classification is attained by recognizing under a single head an entire phylum. Difficulties will be met in applying the principle, owing to the near approach of the first ancestor of a phylum to the parent phylum (unless the origin of phyla should prove to be much more sudden than has been heretofore generally supposed). In practice it is clearly safe to recognize a phylum under a common head as far toward its point of origin as the evidence available permits the line to be with certainty determined. Thus, with the dragon-flies, there is apparently no doubt of the origin of the phylum as a distinct line in Carboniferous or pre-Carboniferous time and continuing to the present time. They are therefore entitled to a group name distinctive of the phylum as a whole.

Regarding the relative rank to be assigned the Protodonata, whether ordinal as proposed by Handlirsch* or subordinal, I would urge again what has been shown above, namely, that the main veins of the wings of the Coal Measures and Permian dragon-flies present an arrangement in agreement in their major characters with that of both Mesozoic and modern dragon-flies. The differences found are due to the specialization of cross veins, with which are associated minor changes in the direction of some of the main veins. These secondary differences are to my mind insufficient characters on which to base ordinal rank. The characters which are now known to exist entitle the Protodonata in my view to not more than subordinal rank. According to this view the order Odonata consists of three suborders, as follows: Protodonata, Zygoptera, and Anisoptera. The term Odonata is thus still available as an ordinal term, covering the Odonate phylum as a whole.

* Revision of American Paleozoic Insects, Proc. U. S. Nat. Museum, vol. xxix, p. 689, 1906.

Art. XXV. — *The Analysis of Dithionic Acid and the Dithionates;* by R. Harman Ashley.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cxlvii.]

According to the method of analysis employed by Dymond and Hughes* in the examination of potassium dithionate, obtained by these investigators as a product of the interaction of potassium permanganate and sulphur dioxide, a weighed amount of the dithionate is dissolved in water, the solution is introduced into a partially vacuous closed flask containing hydrochloric acid, and, after heating, iodine is run in to determine the sulphur dioxide. In this action of hydrochloric acid decomposition takes place according to the equations

$$BaS_2O_6 + 2HCl = H_2S_2O_6 + BaCl_2$$
$$H_2S_2O_6 = H_2SO_4 + SO_2.$$

The sulphur dioxide formed is calculated in accordance with the expression

$$SO_2 + I_2 + 2H_2O = H_2SO_4 + 2HI.$$

It is to be noted, however, that the procedure of Dymond and Hughes according to which iodine is introduced into the solution of sulphur dioxide was long ago criticized by Finkener,† and for it has been substituted the method suggested by Finkener and elaborated by Volhard‡ according to which the solution of sulphur dioxide or the sulphite is introduced slowly from a burette into the iodine solution, the purpose being to obviate the establishment of a secondary reaction

$$SO_2 + 4HI = 2HO_2 + S + 2I_2.$$

It seemed desirable therefore to study the decomposition of dithionates by boiling with hydrochloric acid under conditions which would permit the estimation of the evolved sulphur dioxide by bringing it into action in small amounts upon an excess of iodine, in accordance with the principle of the Finkener-Volhard process.

Barium dithionate was chosen as a suitable salt for investigation. It was prepared in the following manner: Manganese dioxide suspended in water was treated with sulphur dioxide gas in a vessel surrounded with melting ice. After this treatment the solution was made alkaline with an excess of barium hydroxide to remove sulphates and sulphites as

* J. Chem. Soc., lxxi, 314-318.
† Finkener-Rose, Quant. Anal., vi Auf., p. 837.
‡ Ann. Chem. Pharm., ccxlii, 94.

well as to convert the manganese dithionate to barium dithionate. The excess of barium hydroxide was removed by introducing carbon dioxide and boiling to break up any acid barium carbonate which might have been formed and the solution was filtered. The filtrate from the barium carbonate contained pure barium dithionate, which was obtained in solid form by evaporating this solution.

The salt so prepared gave all the reactions of dithionic acid and had a composition corresponding to the formula $BaS_2O_6 \cdot 2H_2O$. In determining the composition of the salt two methods were used. In the first, the barium was precipitated by sulphuric acid and weighed as barium sulphate; in the second method the salt was introduced into a platinum crucible and blasted to drive off water and sulphur dioxide, the residue being weighed as barium sulphate.

A salt of the formula $BaS_2O_6 \cdot 4H_2O$ is said to be formed by slow evaporation.* According to my experience, however, the salt crystallized by evaporation over a flame and that by evaporation at the ordinary temperature in a vacuum over concentrated sulphuric acid had the same composition and both preparations gave on analysis figures corresponding to the formula $BaS_2O_6 \cdot 2H_2O$, the results coming within 0·3 per cent of theory. Crystals of barium dithionate are supposed to effloresce, but no evidence of such action was found in my preparations when the crystals were kept in a weighing bottle at ordinary room temperature.

In studying the decomposition of barium dithionate under the action of hydrochloric acid, crystals of the salt were weighed out and transferred into a Voit flask provided with a separating funnel sealed on. The outlet was connected to a Drexel receiver containing a known amount of standardized iodine, and the outlet of this receiver was provided with a trap containing a solution of potassium iodide. Water was first run into the Voit flask through the separating funnel and the salt was dissolved by the aid of heat. Acid was next run in through the separating funnel and the whole was boiled, a current of carbon dioxide being employed to sweep the sulphur dioxide into the iodine. Hydrochloric acid was added from time to time through the separating funnel to keep up the volume of the liquid and the concentration of the acid. After the operation had proceeded for the times noted, the whole was disconnected and the iodine remaining was determined by means of sodium thiosulphate with starch as an indicator. Results of experiments conducted in this manner are given in Table I.

* Watt's Dict., vol. iv, p. 696.

TABLE I.

Decomposition of barium dithionate by boiling with hydrochloric acid.

No.	S_2O_5 taken. grm.	I value of S_2O_5 taken. grm.	I taken. grm.	I value of $Na_2S_2O_3$ required. grm.	S_2O_5 found. grm.	Errors in I. grm.	Errors in S_2O_5. grm.	Time. min.
1	·0854	·1898	·5721	·3782	·0872	+·0041	+·0018	90
2	·1298	·2885	·5846	·2920	·1316	+·0041	+·0018	90
3	·1429	·3177	·5778	·2607	·1426	−·0006	−·0003	45
4	·1042	·2317	·5765	·3468	·1033	−·0020	−·0009	60
5	·1031	·2293	·5884	·3557	·1047	+·0034	+·0016	60
6	·0704	·1564	·5751	·4228	·0685	−·0041	−·0019	60
7	·0778	·1729	·6194	·4637	·0700	−·0172	−·0078	60
8	·1043	·2319	·5726	·3395	·1048	+·0012	+·0005	30
9	·1043	·2319	·5892	·3548	·1054	+·0025	+·0011	60
10	·1042	·2317	·6110	·3849	·1017	−·0056	−·0025	105

The irregularity of these results may conceivably be due to one or more of three different reasons. In the first place, it may be that the decomposition of the dithionic acid is not complete, and that this may be so is shown by the fact that after the liquid in experiment 10 was boiled for an hour and three quarters and filtered from the precipitated barium sulphate, the addition of sulphuric acid caused further precipitation of barium sulphate. Secondly, it may be that some of the sulphur dioxide escapes absorption in the receiver if the current of carbon dioxide is passed through the system too rapidly. Thirdly, the concentration of the hydrochloric acid in the receiver tends, as is well known, to render the titration of the residual iodine by sodium thiosulphate less exact and the starch iodide less delicate as an indicator.

To eliminate the concentration of acid in the receiver, in the following experiments sulphuric acid was substituted for hydrochloric acid in the Voit flask. A weighed amount of barium dithionate was introduced into the Voit flask and there dissolved in water. Sulphuric acid was run in through the separating funnel and the mixture then boiled, the sulphur dioxide being collected in the Drexel receiver, trapped as before with potassium iodide. A slow current of carbon dioxide was driven through the system to sweep the sulphur dioxide into the iodine and to prevent any sucking back. When boiling had been carried so far that fumes of sulphuric acid began to appear the operation was stopped and the excess of iodine remaining was determined by means of sodium thiosulphate, starch iodide being used as an indicator. Results of experiments carried out in this manner are given in Table II.

TABLE II.

Decomposition of barium dithionate by boiling with sulphuric acid.

No.	S_2O_5 taken. grm.	I value of S_2O_5 taken. grm.	I taken. grm.	I value of $Na_2S_2O_3$ required. grm.	S_2O_5 found. grm.	Errors in I. grm.	Errors in S_2O_5. grm.	Time. min.
1	·1039	·2310	·5759	·3435	·1045	+·0014	+·0006	20
2	·1046	·2326	·5708	·3372	·1051	+·0010	+·0005	28
3	·1039	·2311	·5740	·3435	·1037	−·0006	−·0002	34
4	·1033	·2297	·5701	·3387	·1041	+·0017	+·0008	45
5	·1721	·3827	·5712	·1876	·1726	+·0009	+·0005	35
6	·1719	·3820	·5702	·1894	·1713	−·0012	−·0006	50
7	·1726	·3838	·5734	·1898	·1726	−·0002	·0000	12
8	·1724	·3832	·5727	·1885	·1728	+·0010	+·0004	10
9	·1721	·3826	·3727	·1886	·1728	+·0015	+·0007	10
10	·0692	·1539	·3130	·1599	·0689	−·0008	−·0003	12
11	·0350	·0777	·3109	·2323	·0354	+·0009	+·0004	4
12	·2061	·4582	·6205	·1632	·2057	−·0009	−·0004	15
13	·2402	·5340	·6215	·0862	·2408	+·0013	+·0006	15

These results show that dithionic acid may be determined by boiling with sulphuric acid and estimating the sulphur dioxide liberated, while when hydrochloric acid is used the results are far from satisfactory.

There are three reasons why sulphuric acid should work better than hydrochloric acid in this process:

First, when sulphuric acid is added to the solution of barium dithionate, barium sulphate is precipitated and dithionic acid is left in free condition, this reaction proceeding at once to completion because the barium sulphate formed is removed from the system. It would seem that when hydrochloric acid is used the dithionic acid is completely liberated only by a gradual change in the conditions of equilibrium.

Second, when the solution containing sulphuric acid is boiled, the water is driven off, the concentration of the solution increases and the high temperature of the fuming point of sulphuric acid is reached. Under such conditions the decomposition of the dithionic acid is rapid and complete, the time being dependent upon the original dilution of the solution. In one case, No. 11, the operation was ended in four minutes.

Third, no appreciable amount of acid distils over from the Voit flask into the receiver containing the iodine to interfere with the back titration with sodium thiosulphate, the only acid present being that produced by the oxidation of the sulphur dioxide. Under these conditions the starch indicator acts sharply, which is not the case when hydrochloric is used.

SCIENTIFIC INTELLIGENCE.

Geology.

1. *Ueber Parapsonema cryptophysa Clarke und deren Stellung im System;* von Th. Fuchs. Centralbl. f. Min., etc., 1905, pp. 357–359.—In 1902, Clarke (54th Ann. Regents Rept. N. Y. State Mus., pp. 172–178) described a most perplexing and highly interesting fossil, under the title "Paropsonema cryptophya: A peculiar echinoderm from the Intumescens-zone (Portage beds) of western New York." Fuchs reviews Clarke's paper and adds that "the entire organization is wholly different from all known Echinodermata and can not be readily compared with any. According to my view, we here have the remains of quite another animal, namely, a medusa, related to *Porpita*."

A very excellent cast of one of Clarke's finest specimens was presented by him to Peabody Museum of Yale University. It does not possess unmistakable echinoderm structures, although the radial parts, with their numerous transverse divisions, do in a way recall the ambulacra of Paleozoic echinoids. Unlike these, however, the radial parts of *Paropsonema* are bifurcated, in adult specimens, as many as four times. Then, too, the upper surface is wholly unlike the lower and is not made up of plates. Further, associated with this fossil crinoids occur and in these the calcareous plates are preserved, while in *Paropsonema* there is nothing other than a cast or the infiltrated filling of the cavities. Fuchs states that the lower surface "has a great number [60 to 80] of arched folds that increase by division or intercallation of new radii and carry the individual polyps. . . . Should it prove that my view is the correct one, we then have in this organism, as far as I am aware, the first evidence of a fossil siphonophore related to *Porpita*."

The present writer likewise thinks it more probable that *Paropsonema* is related to *Porpita* and *Velella* (see Agassiz, "The Porpitidæ and Velellidæ," Mem. Mus. Comp. Zool., Harvard, VII, No. 2, 1883) rather than to any echinoderm. C. S.

2. *Phylogeny of the Races of Volutilithes petrosus;* by Burnett Smith. Proc. Acad. Nat. Sci. Phila., 1906, pp. 52–76, and one plate.—This interesting paper gives the results of a study based on many specimens of *Volutilithes petrosus* derived from nine localities, and on four other species. The forms of *Volutilithes* first appear in non-normal marine deposits (Lignitic), having radiated from the outer deeper normal marine waters. These peripheral races undergo "a course of evolution which was a direct reflection of their unfavorable environment. . . . The senility becomes more and more extreme with the course of time." The normal, slow and even development takes place in the more open favorable environment. C. S.

3. *Notes on some Jurassic Fossils from Franz Josef Land, brought by a Member of the Ziegler Exploring Expedition;* by R. P. Whitfield. Bull. Amer. Mus. Nat. Hist., May, 1906, pp. 131–134, 1 pl.—The notes relate to Ammonites, Mollusca, and land plants.

SAMUEL LEWIS PENFIELD, Professor of Mineralogy in the Sheffield Scientific School of Yale University, died August 12, at Woodstock, Conn., where he had been passing the summer. He was in the 51st year of his age. He had been for some time in bad health. A notice of the life and work of this distinguished mineralogist will appear in a near number of this Journal.

CRYSTALLOGRAPHY.

Our new Catalogue XIX, with many illustrations, has just come out (post free on application). Of its contents, the following may be mentioned:

1. *New Collection of 416 Crystal-models of wood*, containing all the crystal forms and combinations represented by illustrations in the 4th ed. of P. Groth's "Physikalische Krystallographie, - - - - - - - - 550 Marks.
2. *Large Collection of 928 Crystal-models of wood* to illustrate the crystal-forms of the minerals; arranged by Prof. Dr. Hintze, - - - - - - - - - - - 1800 "
3. *The Brush-Penfield Collection of 225 Crystal-models of wood* for illustrating Chapter V of the Brush-Penfield "Determinative Mineralogy, etc.," - - - - - 230 "
4. *New Collection of 450 Crystal-models of paste-board*, systematically arranged by Professor Dr. K. Vrba, - 950 "
5. *New Models of Calcite-Rhombohedrons, Nicol-Prisms, Planes of Symmetry, Optical Wave Surfaces, Optical Indicatrix, Sciodromes, Crystallographic Axes.*
6. *Stands for crystal-models* in various forms and constructions.

LANTERN SLIDES

For Lectures on Petrology and Geology.

The new edition of *H. Rosenbusch text-book* (by H. Rosenbusch and E. A. Wülfing), Vol. I, "Mikroskopische Physiographie der Mineralien," has just come out in two parts, each of which contains a considerable number of photographic reproductions showing the microscopical features and structures of the rock-forming minerals. By the kindness of the author and publisher we have been able to prepare *lantern slides of the original photos*, which we now offer in two sets of 72 slides each; collection A, representing the figures on the plates IV–XV of part I; collection B, those of the plates I–XII of part II.

Collection A: Growth of crystals, inclusions, aggregates, deformations, etc., 72 slides, - - - - - - 100 Marks.
Collection B: The rock-forming minerals, 72 slides, - - 100 "

We also remind the reader of the following collections of lantern slides:

I. *Petrological*, arranged by Professor Dr. K. Busz, in Münster, i. W.

1. 50 slides; mode of occurrence of the rock-forming minerals, - - 70 Marks.
1a. 20 slides; do. crossed nicols, - - - - - - 28 "
2. 80 slides; microstructure of the rock-forming minerals, - - 112 "
3. 36 slides; the structures of rocks, - - - - - - 50 "
4. 100 slides; systematic collection (according to Rosenbusch) of typical rocks, - - - - - - - - - 140 "
4a. 75 slides; do. crossed nicols, - - - - - - - - 105 "

II. *Geological*, arranged by Professor Dr. van Calker, in Groningen.

1. 30 slides; Historical Geology, type-fossils, - - - - - 42 Marks.
2. 50 slides; Tectonic Geology, - - - - - - - - 70 "
3. 60 slides; Volcanism, - - - - - - - - - 84 "

III. *Paleontological*, arranged by Professor Dr. van Calker, in Groningen.

1. 30 slides; Paleontological problematics and pseudo-fossils, - - 42 Marks.
2. 25 slides; Protozoa (Foraminifera, Radiolaria, etc.), - - - 35 "
3. 20 slides; Spongiae, - - - - - - - - - 28 "
4. 22 slides; Brachiopoda, - - - - - - - - - 31 "
5. 40 slides; Lamellibranchiata, - - - - - - - - 56 "
6. 50 slides; Pisces, - - - - - - - - - 70 "
7. 12 slides; Amphibia, - - - - - - - - - 17 "
8. 50 slides; Sauropsida (Reptilia and Aves), - - - - - 70 "
9. 70 slides; Mammalia, - - - - - - - - - 100 "

Collections of Minerals, Fossils, Meteorites purchased for Cash or Exchanged.

The new spring bulletin (*Minerals*) has just been published and will be sent free on application.

DR. F. KRANTZ,

RHENISH MINERAL OFFICE,

BONN-ON-RHINE, GERMANY.

ESTABLISHED 1833. ESTABLISHED 1833.

ESTABLISHED 1851.

EIMER & AMEND

18th Street and Third Avenue, NEW YORK.

Manufacturers and Importers of

C. P. Chemicals and Chemical Apparatus

Sole Selling Agents for

KUNZITE

(See this Journal, xvi, 264, September, 1903.)

The lately discovered lilac-colored transparent Spodumene from Pala, California.

Nice crystals from $1.00 upwards per specimen.

Kunz-Baskerville Radium Mixtures

CURIE'S RADIUM SALTS

In intensities from 40× activity up to the highest.

Spinthariscopes, Bar.-Platin. Cyanide Screens, etc.

BAKER & CO.

METALLURGISTS IN PLATINUM

410 N. J. R. R. AVE., NEWARK, N. J.

Beg to announce that they are the sole Licensees for the manufacture of the Shimer Crucible.

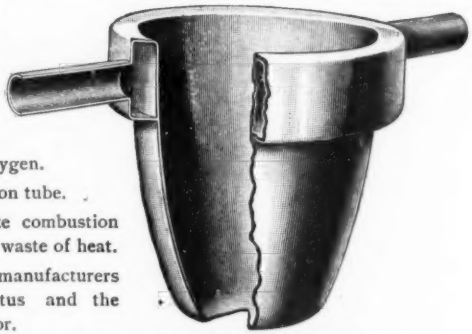
Having the following advantages:

It uses air instead of oxygen.

It requires no combustion tube.

It secures the complete combustion of graphite. There is no waste of heat.

We are also the sole manufacturers of the Tucker Apparatus and the Howard Density Regulator.



SHIMER CRUCIBLE

Our "Data Concerning Platinum, Etc.," and our brochures on the above specialties, should be in every chemist's library. They are free on request.

N. Y. OFFICE, 120 LIBERTY STREET

"GOLD MEDAL—Lewis & Clark Centennial Exposition—Portland, Oregon, 1905."

ROCK AND MINERAL SECTIONS

ON STOCK AND TO ORDER

Sets illustrating—Rock-forming Minerals—Optics of six systems of Crystallization—Feldspars—Common Rocks—Coals. Complete collections of Rock Sections. Single Rock and Mineral Sections.

MICRO-PHOTOS TAKEN | **PETROLOGICAL ANALYSIS MADE.**

WRITE FOR CATALOGUE.

W. HAROLD TOMLINSON,

PETROLOGICAL LABORATORY,

44 E. Walnut Lane, - Germantown, Phila., Pa.

THE AMERICAN NATURALIST

A Monthly Journal Devoted to the Natural Sciences in Their Widest Sense.

Since the foundation in 1867 by four of the pupils of Louis Agassiz, THE AMERICAN NATURALIST has been a representative American magazine of Natural History and has played an important part in the advancement of science in this country.

The journal aims to present to its readers the leading facts and discoveries in the fields of Anthropology, General Biology, Zoology, Botany, Paleontology, Geology and Mineralogy, and the various sub-divisions of those subjects.

Annual Subscription, $4.00 net, in advance. Single Copies, 35 Cents.
Foreign Subscription, $4.60.

GINN & COMPANY, Publishers.

29 BEACON STREET, BOSTON, MASS.

6t., Feb. '03—alt.

DANA'S SERIES OF MINERALOGIES.

PUBLISHED BY

JOHN WILEY & SONS,

43 AND 45 EAST 19TH STREET, NEW YORK.

NEW "SYSTEM OF MINERALOGY," 1837-1868.

Sixth Edition. Entirely Rewritten and Much Enlarged. With Appendix I, Completing the Work to 1899. Large 8vo, lxiii + 1,219 pages, illustrated with over 1,400 figures. Half leather, $12.50. APPENDIX I, $1.00.

A TEXT-BOOK OF MINERALOGY.

With an Extended Treatise on Crystallography and Physical Mineralogy. New Edition, Entirely Rewritten and Enlarged. 8vo, viii + 593 pages, 1,008 figures and a colored plate. Cloth, $4.00.

MINERALS AND HOW TO STUDY THEM.

A Book for Beginners in Mineralogy. 12mo, vi + 380 pages, 319 figures. Cloth, $1.50.

CATALOGUE OF AMERICAN LOCALITIES OF MINERALS.

Reprinted from Sixth Edition of the System. Large 8vo. Cloth, $1.00.

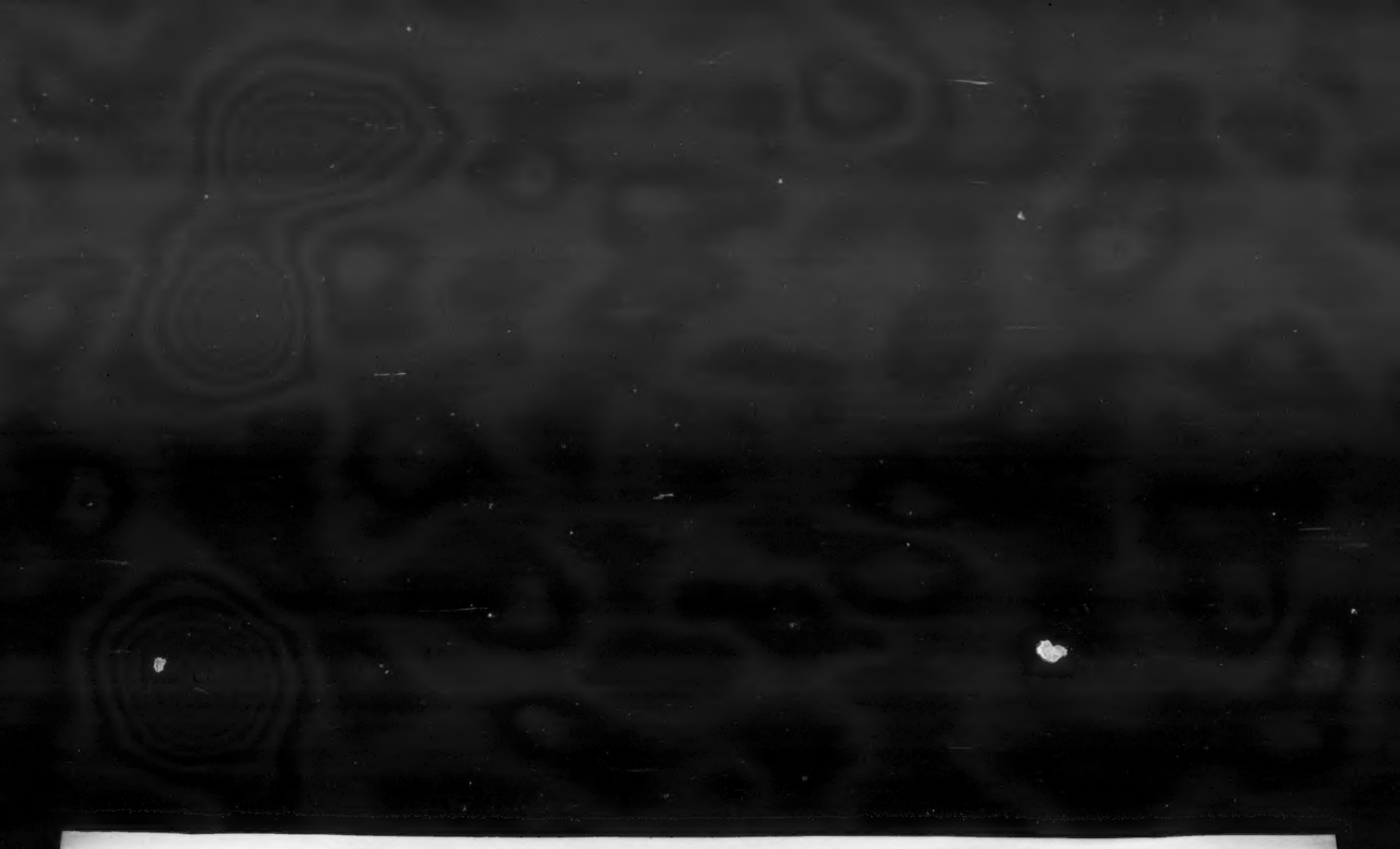
MANUAL OF MINERALOGY AND PETROGRAPHY.

12mo, ix + 517 pages, fully illustrated. Cloth, $2.00.

The American Journal of Science

ESTABLISHED BY BENJAMIN SILLIMAN IN 1818.

CONTRIBUTORS should send their articles two months before the time of issuing the number for which they are intended. The title of communications and the names of authors must be fully given. Notice is always to be given when communications offered have been, or are to be, published also in other Journals.

Thirty separate copies of each article will be furnished to the author free of cost and without previous notice from him. They will be provided with a plain cover (but with reference to volume and year). If the author orders separate copies, they will be understood to be in *addition* to the thirty mentioned above, and he will receive a bill for the extra expense involved, as also for that of a printed cover (with title, etc.), when this is *specially ordered*. These charges will conform to the following schedule; the rates will be somewhat increased if the article is accompanied by plates.

No. Copies.	50	100	200	300	500
8 pages	$2.25	$2.75	$3.50	$4.25	$5.50
16 "	3.50	4.25	5 25	6.25	8.00
24 "	4.75	5.75	7.00	8.25	10.50
Cover	$1.00	$1.25	$1.75	$2.25	$3.00